THE EARTH AND ITS LIFE

BY

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PREFACE

This text is published in connection with an experiment conducted by the Harvard Graduate School of Education and the University Film Foundation, under a joint grant from the Carnegie Foundation for the Advancement of Teaching.

The earnest coöperation of a number of workers has been of literally invaluable assistance in the making of the book. The authors wish to acknowledge their indebtedness to Professor Kirtley F. Mather of the Harvard Division of Geology and to Dr. Albert E. Navez of the Harvard Biological Institute for their assistance in achieving scientific accuracy in the text. At the same time the authors wish explicitly to absolve these men from any responsibility for whatever errors may yet remain in the book.

Mr. John A. Haeseler, Director of the University Film Foundation, has given willing assistance considerably beyond that required by his connection with the experiment itself, and has had much to do with the success of this part of it.

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Critical assistance and valuable suggestions have been contributed by Mr. Robert A. Kissack, Jr., and by Miss Charlotte Croon.

For illustrations used in the text, the authors are deeply indebted to the following: Mr. L. B. Andrews, of the Harvard College Observatory; Professor R. A. Daly, of the Harvard Division of Geology; Professor W. H. Weston, Jr., of the Harvard Division of Biology; Dr. Guy Elliott Mitchell, of the U. S. Geological Survey; Mr. N. P. Tucker, of the U. S. Department of Agriculture; Mr. C. E. Randall,

of the U. S. Forest Service; Mr. H. H. Bennett, of the U. S. Bureau of Chemistry and Soils; Mr. Elwood Mead, of the U. S. Bureau of Reclamation; Dr. George H. Sherwood, of the American Museum of Natural History; Mr. Louis C. Bierweiler, of the Harvard Botanical Museum; and Mr. Charles R. Williams of the Harvard Museum of Comparative Zoölogy.

FOREWORD

THE purpose of this book is to supply basic instructional material for a part of first-year general science as offered in the junior high school. It aims directly at general science, rather than being a series of specialized treatises. The early sections on the materials of geology and physiography are presented with a view to showing how the Earth came to be a suitable place for the existence of the living things which are dealt with in the later chapters. Throughout these later chapters, the dependence of these living things upon their environmental circumstances has been kept constantly to the fore.

The book is primarily designed for ninth-grade students who have had less than a year of previous work in general science. If presented to students of some other level, it would probably be found suited to those of more maturity and background rather than to those of less. At the level for which it is designed, the material should occupy not less than five school periods a week for five weeks.

The expository material of the book has been supplemented by questions which appear both at the ends of the chapters, and in the legends of many of the illustrations. Not all of these questions can be answered by reference to the textual material of this book alone. Those which cannot are inserted for purposes of outside study, should the teacher choose to assign any. The questions have been selected with an eye to their stimulating nature and to their probable educational effectiveness.

As new or technical words have been introduced they have been accompanied by definitions or familiar synonyms. The need for a glossary has thus been avoided. In addition, two sorts of words have been avoided wherever possible. One sort is the scientific word for which there is a common word meaning almost the same thing. *Bergeschrund* is an example. The other type avoided is the word

whose common meaning is misleadingly different from its scientific meaning. *Fault,* in the geological sense, provides an example.

The expository material is designed to be self-explanatory, without specific reference to the illustrations and experiments which accompany it.

The series of eight reels of sound motion pictures which parallel this text has been produced by the University Film Foundation under the same pedagogical direction which guided the construction of the book itself. The motion pictures are not based on this book. Neither is the book based on the motion pictures. Instead, both the films and the book were produced from the same basic script, under the same guidance, with the aim that they should be mutually supplementary; but each is designed to be self-contained and self-sufficient. No reference to the films appears elsewhere in this text, and no reference to the text is made in the films.

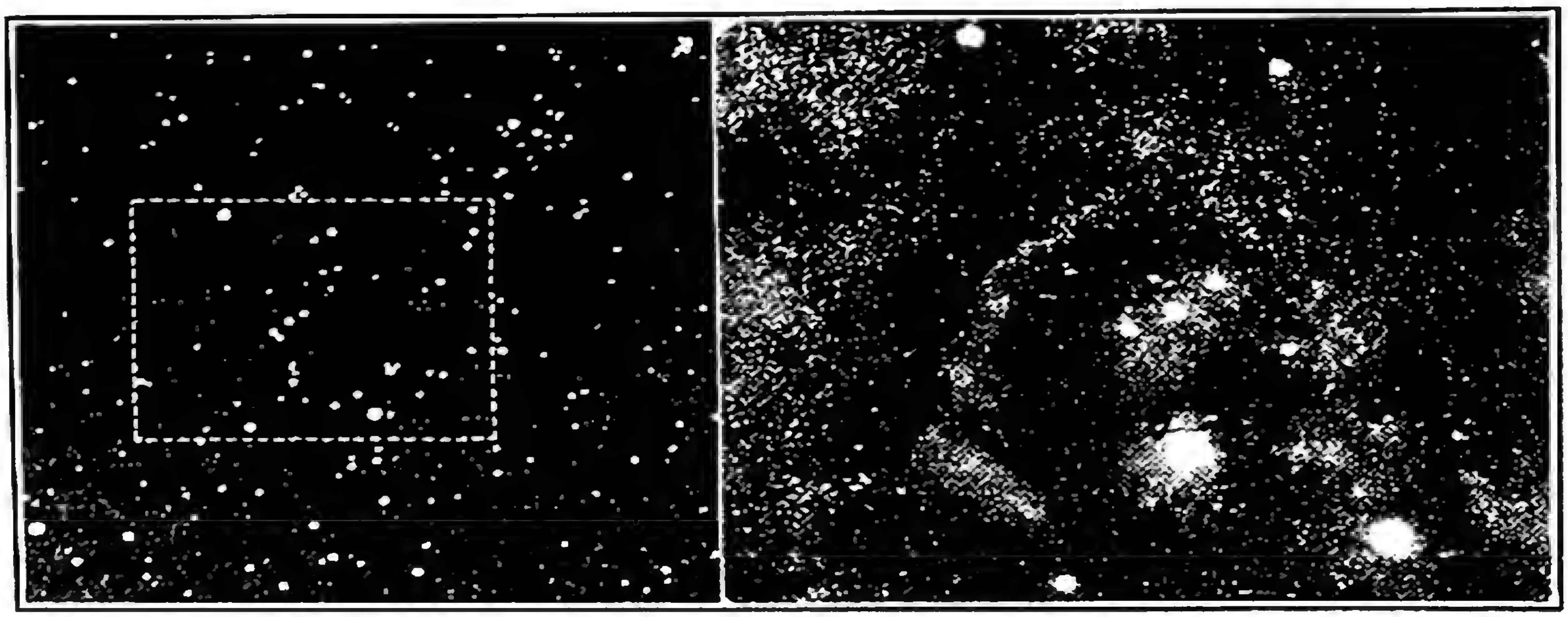
THE EARTH AND ITS LIFE

CHAPTER I

THE EARTH AND ITS ROCKY CRUST

The Earth and the Universe

Everyone has looked at the sky on a clear night. About two thousand stars can be seen. There are about three thousand more that could be seen if they were not hidden by the Earth. And there are millions more, too faint to be seen with the eye alone, but visible to astronomers with their telescopes. Our Sun is just one of the smaller of these stars; it seems larger than the others only because it is



(Courtesy Harvard College Observatory)

Figs. 1 and 2. The sky in the neighborhood of Orion is shown at the left as it appears to the unaided eye. Note how few stars are visible in the dotted rectangle. On the right is a telescopic photograph of the area in this rectangle. Note the multitude of stars visible when the telescope is used.

thousands of times closer. The stars are separated by enormous stretches of empty space. Even light itself takes years to make the journey from one star to another, and light goes so fast that it could travel seven times around the Earth in a single second.

Surrounding the Sun at distances varying from 36 million to about 4,000 million miles, are the nine planets. The Earth is one of these planets. It is about 93 million miles from the Sun, a distance so great that a fast airplane going 180 miles an hour would require 59 years to make the trip. Yet even this distance is small as compared to the distances between the stars. Light, which takes years to go from one star to another, comes from the Sun to the Earth in about eight minutes. The planets move about the Sun in paths or orbits which are ellipses or ovals, but which are so nearly like circles that no one could tell the difference without making accurate measurements.

Some of the planets have smaller bodies moving in orbits about them in turn. These smaller bodies are called moons. The Earth has one moon, which is about one fourth as large as itself. The Moon is 240,000 miles away, a distance such that our fast airplane traveling 180 miles per hour would reach it in a few days less than two months. Some of the planets have several moons, and others have none.

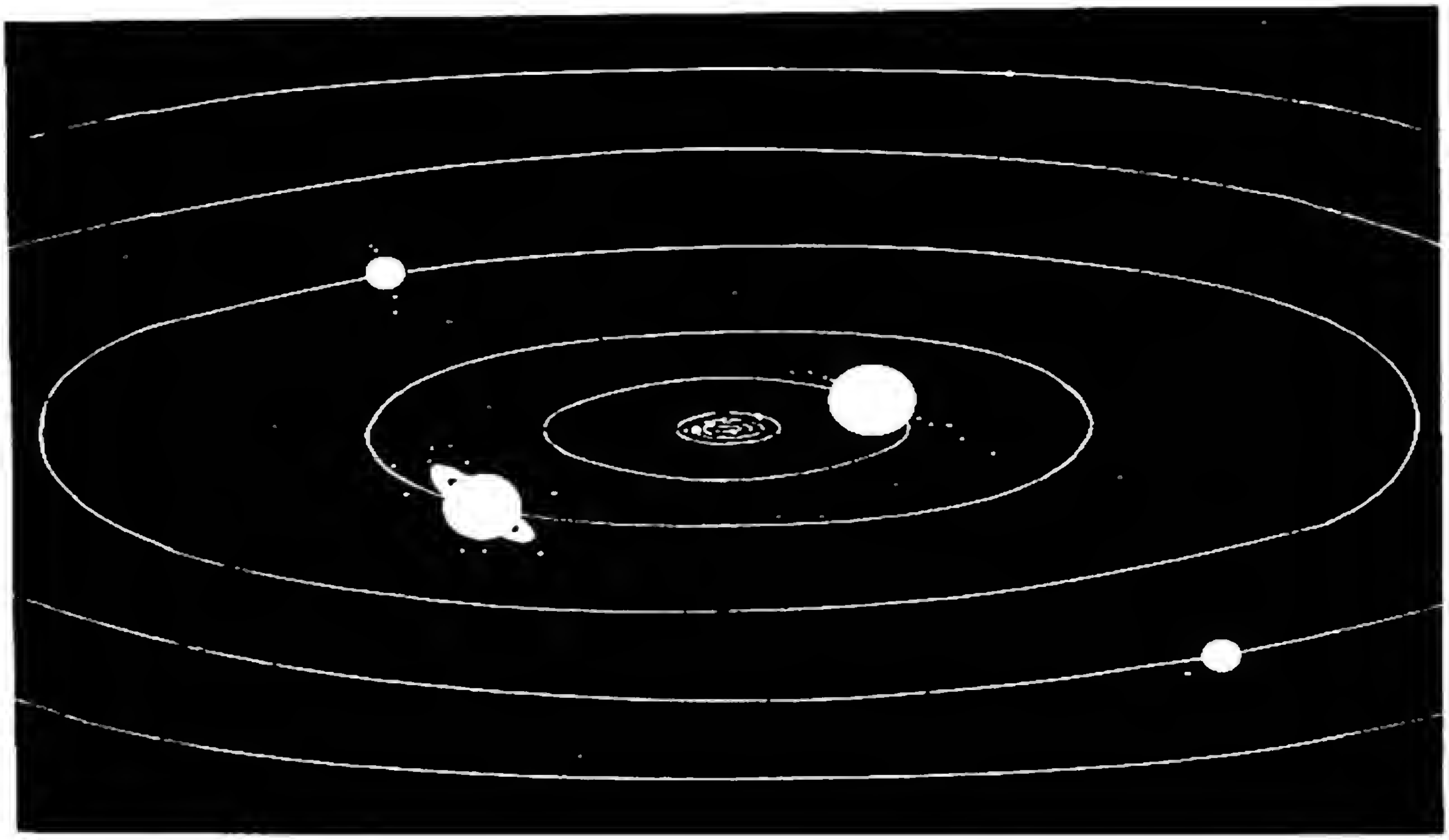
The Sun often looks about the size of an orange. If it really were that size (three inches in diameter), the Earth on the same scale would be about as big as a pinhead or a grain of coarse sand, and would be about 27 feet away. The Moon would then be the size of a grain of fine sand, and about five sixths of an inch from the Earth. The nearest star would on this scale be more than a thousand miles away.

The Sun, the planets, their moons, and various smaller bodies taken together make up the Solar System. Most of the stars are believed not to have solar systems. Some astronomers, in fact, think it is unlikely that any other star in the whole Universe has a system of planets and moons like ours.

The Formation of the Earth

No one knows how the Earth first came into being nor just how old it is, but it seems fairly certain that the ma-

terial of which the Earth is composed was long ago thrown out from the Sun and that in the distant past it was much hotter than it is at present. Scientists who have been working on this problem believe that the Earth was formed in one of the two following ways.



(Courtesy Harvard College Observatory)

Fig. 3. This diagram shows the nearly circular orbits of the planets as they look in perspective. The planets as shown are far too large for their orbits, but they are the correct sizes in relation to each other. The Sun is not shown. Can you name the planets?

One theory is that many hundred millions of years ago, the Earth was a molten mass, somewhat as the Sun is today. This melted ball was much larger than the Earth we know. Its surface boiled and gave off flaming gases. Then gradually it began to cool. As it cooled it became smaller. Here and there solid masses began to appear—the first rocks. This cooling went on for millions and millions of years, and the solid material came to form a crust over the whole globe. The cooling continued, and the globe shrank to a

smaller size. The crust gradually wrinkled, like the skin of a dried apple. These wrinkles make our mountains.

Another theory is that at first the Earth was a very small body, thrown out from the Sun when another star approached very closely to it. This small Earth nucleus became larger as millions of particles of rock were added to

(Photo by U. S. Forest Service)

Fig. 4. This general view of mountains shows a result of the "wrinkling" of the Earth's surface. No living thing existed when this wrinkling first took place. This picture does not show the Earth as it looked when it first cooled. How do you know?

it from the "star dust" surrounding the Sun. As it grew larger, the pressure on its central portion increased until parts of the Earth's interior were changed into liquid rock or lava. About the time that the Earth became full grown and thus reached its present dimensions, this lava began to spread out upon its surface. Volcanic eruptions were extremely numerous and the outer crust of the Earth was broken and wrinkled.

Whichever method was followed, when the Earth was very young, it is certain that large quantities of gas escaped from the boiling lava at its surface. Some of the gas escaped into outer space, but much of it was held close to the surface of the Earth, forming an atmosphere—the air. As the volcanic fires cooled and the solid outer crust of the Earth became thicker, the air resting upon it was also cooled. In consequence the water vapor in the air began to condense into water. Clouds appeared and rain fell

The water ran down the slopes from high places to low places in the Earth's crust, forming the first streams and rivers. Eventually the water filled up the hollows, forming oceans and lakes.

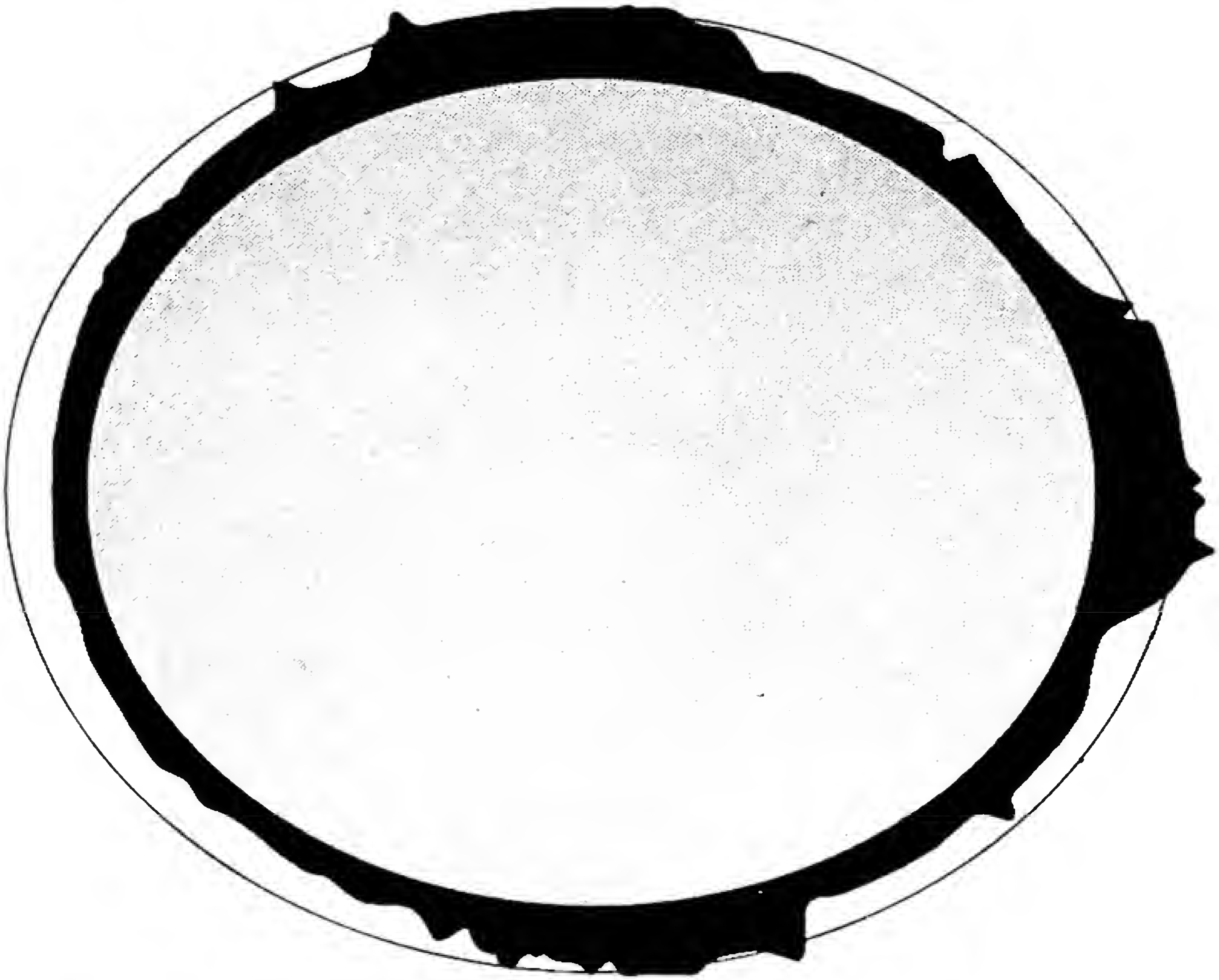


Fig. 5. This drawing shows a cross-section of the Earth at the Equator. No one knows just what the interior of the Earth is like, so that part of the drawing is left blank. The mountains, valleys, and ocean depths are all exaggerated in this drawing, but they are in the right proportion to each other. Can you locate the Pacific Ocean? The Atlantic? The continents?

Now another force began to be important. This was the heat of the Sun. The crust of the Earth had become so thick that the Earth's own heat was bottled up within this crust, breaking forth only rarely in the eruptions of vol-

canoes. But the Sun, being much larger, cooled much more slowly. The heat coming from the Sun caused water to evaporate from lakes and oceans on the Earth, forming new clouds. With small changes in temperature, new rain fell from the clouds, and the water from this rain ran down again into the low places of the Earth, to be evaporated still again into clouds. And so the process went on and on, and is still going on. We call this process, which is repeated over and over, the water cycle.

After millions and millions of years, life appeared. The first forms of life were very simple and very small. No one knows how or why they first came to be. The first living organisms,—animals and plants,—lived either in the warm oceans, or in the moist, warm ground. Different forms appeared and disappeared, until finally those to be seen today were left.

Living things need very special surroundings. They cannot exist for long periods except within the narrow range of temperatures between the boiling point and the freezing point of water. They can continue to live only in an atmosphere that contains oxygen to breathe. They could not exist on a body very many times larger or smaller than the Earth.

It is possible that life may exist on other planets of the Solar System. Some astronomers believe that it does. It is possible that there may be other solar systems with planets that support life. On the other hand, there are those who believe that in the whole great Universe, only our own little speck of an Earth has just the right set of conditions to make it a place where life can exist.

The Earth's Crust

The crust of the Earth is made up mainly of rocks, of which there are many kinds. Some are hard and smooth, others are soft and crumbly, and still others are rough and irregular. If we dig down through the soil anywhere, we shall come finally to solid rock. In some places, such as

mountain tops and ocean cliffs, the bare rock may be seen at the surface of the Earth, without any covering of soil. In other regions the rock may be covered by many feet of soil.

As we go down into a deep mine, the temperature rises. This fact, together with the existence of volcanoes, leads us to think that the interior of the Earth is still hot. It need not be supposed that it is liquid, however, for the immense pressures developed by the weight of the miles of rock on top keep it solid.

Fig. 6. A volcanic explosion The cloud is composed of mixed hot gases and rock particles and is more than a mile high.

Volcanoes

From time to time in different parts of the Earth, a volcano erupts. It sends up great clouds of gas and ashes, and finally melted rock or lava wells up from the interior of the earth through the central pit or crater of the volcano, and flows out over the land. The lava cools slowly, forming a new layer of rock. Rocks formed in this way are called igneous rocks, or fire-rocks. Since the whole Earth was fiery hot at one time, its main crust is built up of igneous rocks.

But most igneous rock is formed from molten rock which does not erupt through the crater of a volcano and flow over the surface of the earth. Instead, a huge mass of molten rock wells up from the interior of the earth, remains a half mile or more below the surface and there, under great pressure from the weight of over-lying material, it cools very slowly into a great solid block of rock. Most igneous rock is formed in this way under pressure and is

called granite. It is very hard and weather-resisting, and takes a high polish. It is much used for monuments and

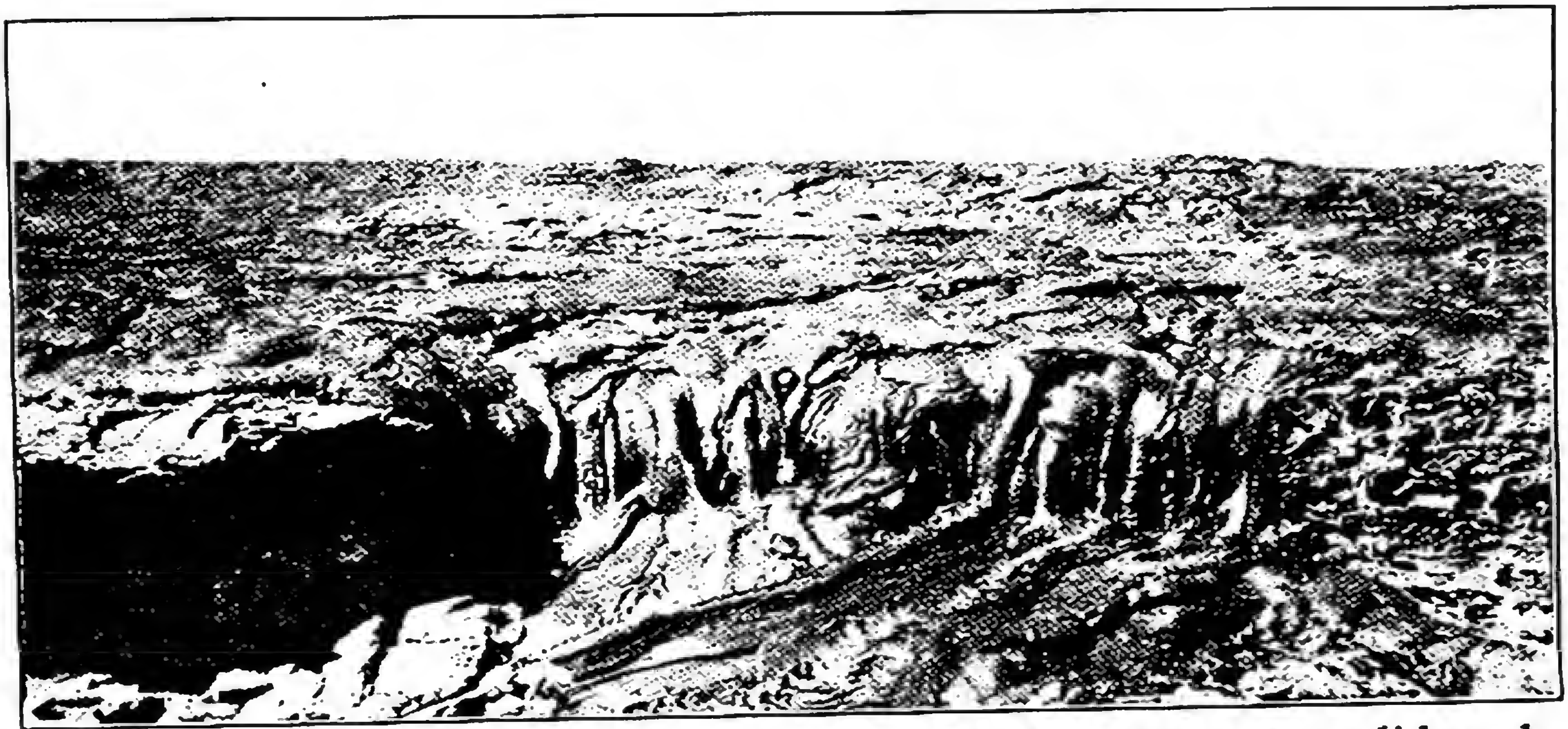


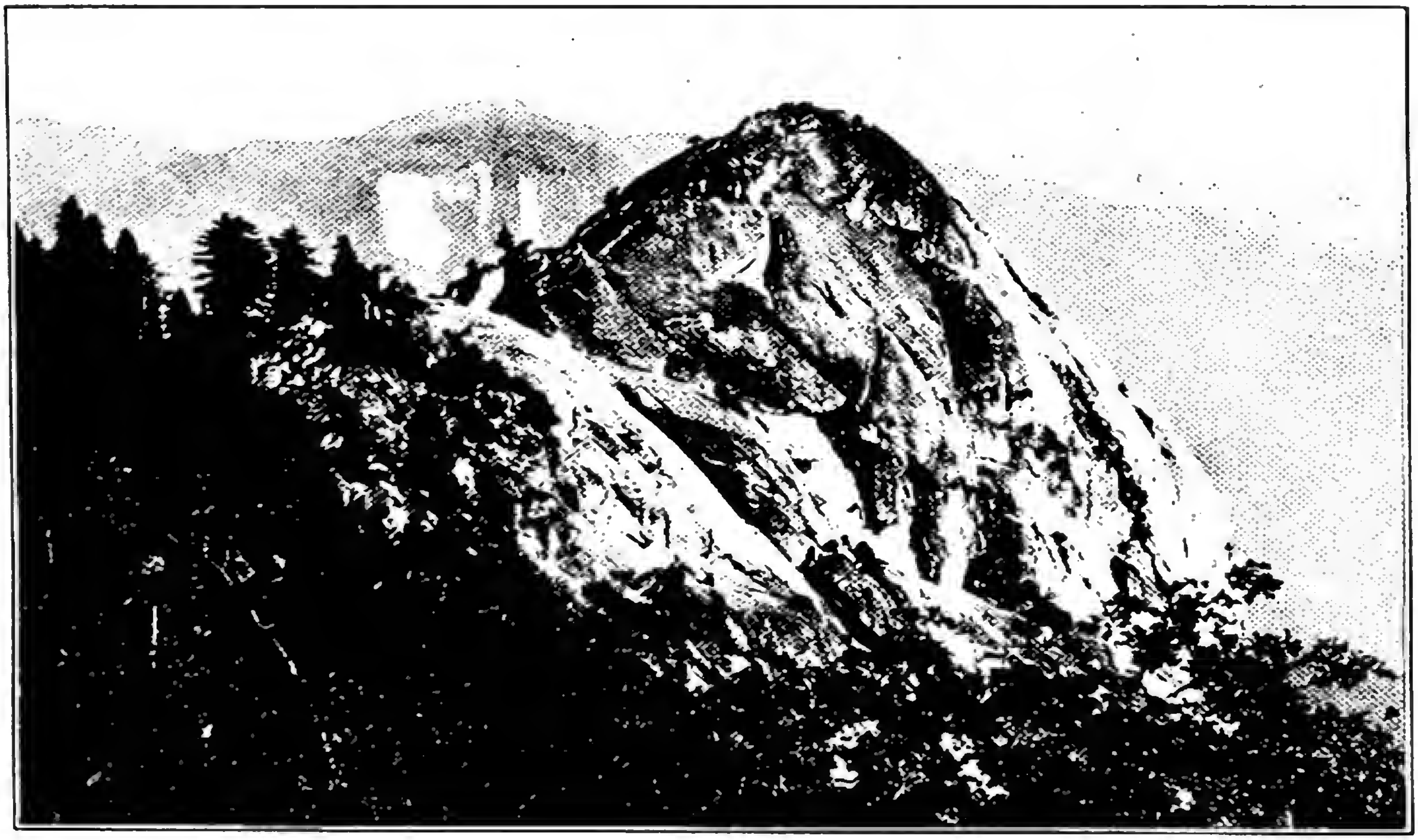
Fig. 7. The lava in this picture has cooled and is now solid rock. Does its appearance indicate that it was once fluid, and that it flowed into its present position?

buildings, where wearing qualities are important. Most rock formed by the cooling of lava erupted from volcanoes is called basalt. Basalt is not as hard or as shiny as granite, mainly because it has cooled much faster.

Sedimentation

As the rains of ages fall on the earth and flow away to the sea, they pick up and carry along particles of sand and mud which wear away the rock. They carry some of these particles to the ocean, where they gradually settle to the bottom. With the passing of centuries the mineral matter dissolved in the water cements these sediments into layers of rock again. Rocks formed in this way are called sedimentary rocks. If the particles making up the rock are largely grains of sand, the rock is called a sandstone. If the streams have deposited fine particles of mud, the resulting rock is called shale.

Many very small animals live in the ocean in the warm shallow parts near the shores. After death, their shells or skeletons sink to the bottom. In the course of thousands



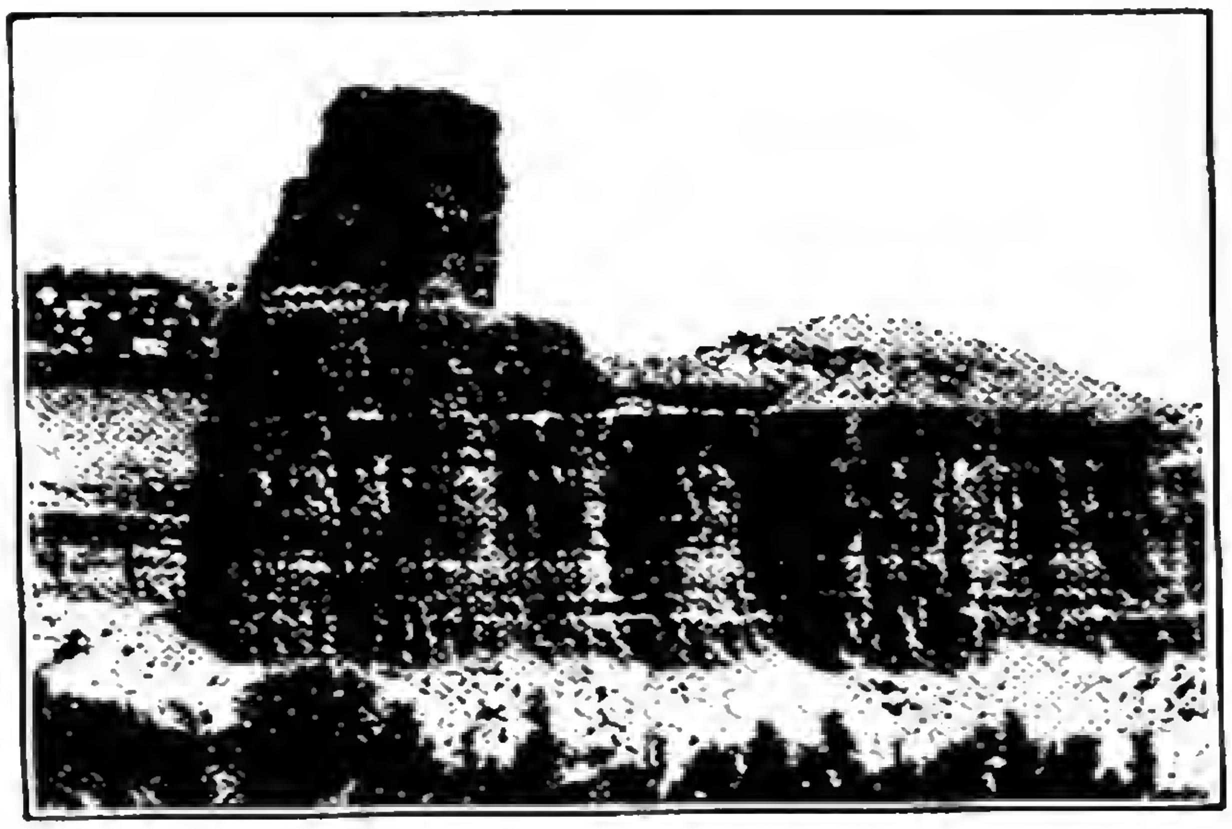
(Photo by U. S. Forest Service)

Fig. 8. This mountain peak is of solid granite—an igneous rock. This sort of rocky prominence is not caused by lava flowing from volcanoes as we see them. The lava from erupting volcanoes is never granite. Does the shape of this peak suggest that it was formed as described in the text?

and millions of years these tiny skeletons may become numerous enough to form another kind of sedimentary rock called limestone. Sedimentary rocks are always found in layers or strata, and for that reason they are often called stratified rocks.

Earth Movements

The crust of the Earth is not entirely stable and motionless. The Earth itself is still shrinking, and its crust is still bending and cracking and wrinkling. This process is extremely slow. Most of the rocks move at the rate of only a few inches a century. Yet it is these very slow



(Photo by U. S. Forest Service)

Fig. 9. These layers of sandstone show the stratified appearance of sedimentary rock. Do you suppose these rocks were formed on the high hill where they are now?

movements which in the course of millions of years have made the ocean basins and the continents. The big wrinkles, which come at weak points in the Earth's crust, are called mountains. Mountains are continuously in the process of formation, sometimes at one point of the Earth's surface and sometimes at another. Forces almost unthinkably great cause the rocks to bend and warp, break and

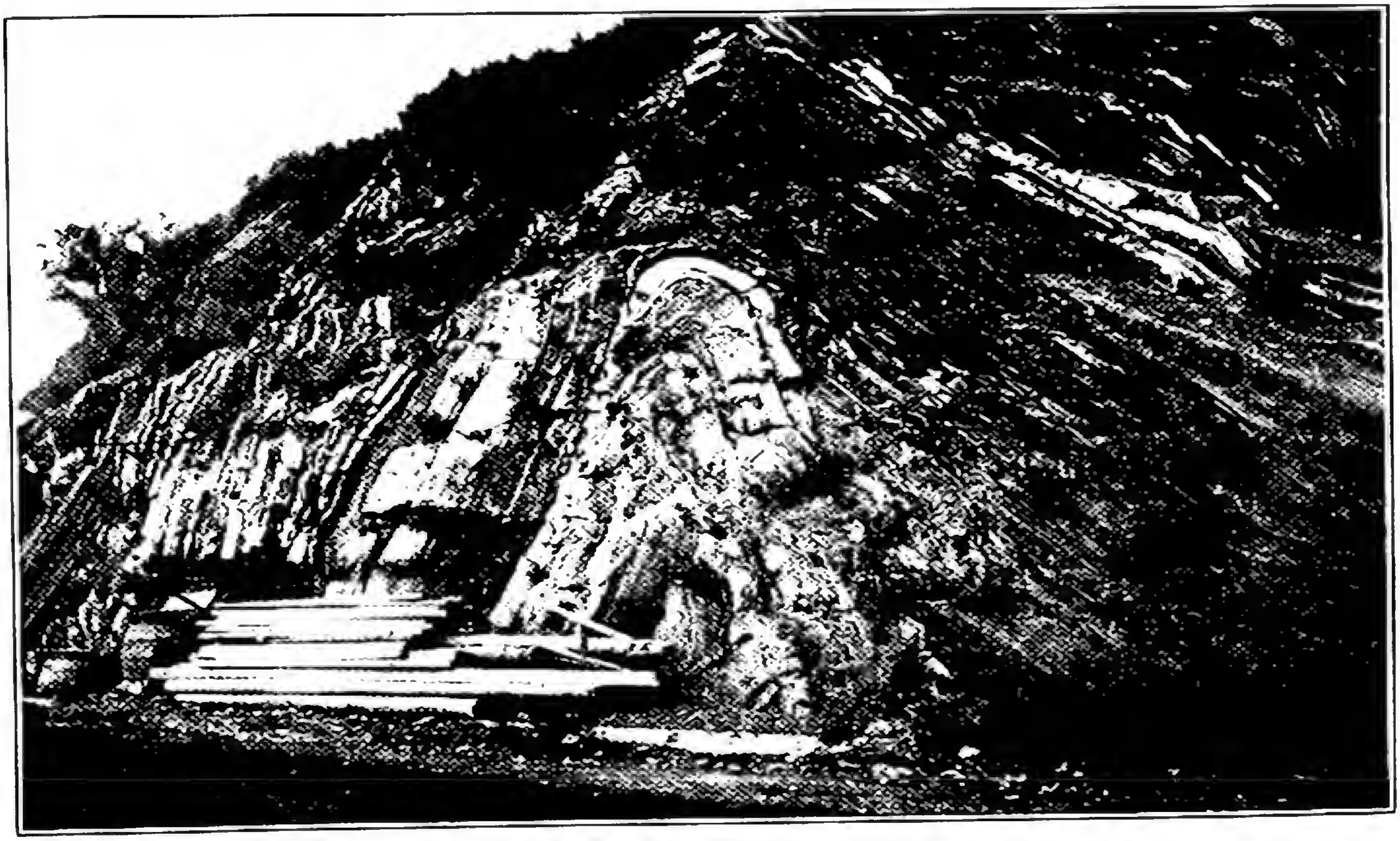


Fig. 10. These rocks were originally laid down in neat, even layers, like those in Fig. 9. Earth movements are responsible for their present bent and folded condition. Can you trace one of the strata up over the arch and down again?

wrinkle. Heat is often generated as a result of the pressure and movement. When rocks are subjected to this pressure and heat for long periods—thousands and perhaps millions of years—they are changed in appearance and texture. Limestone turns into marble, shale into slate, sandstone into quartzite, granite into gneiss, and basalt into schist. These new types are called metamorphic rocks, because they arise by metamorphism, or change, from other rocks.

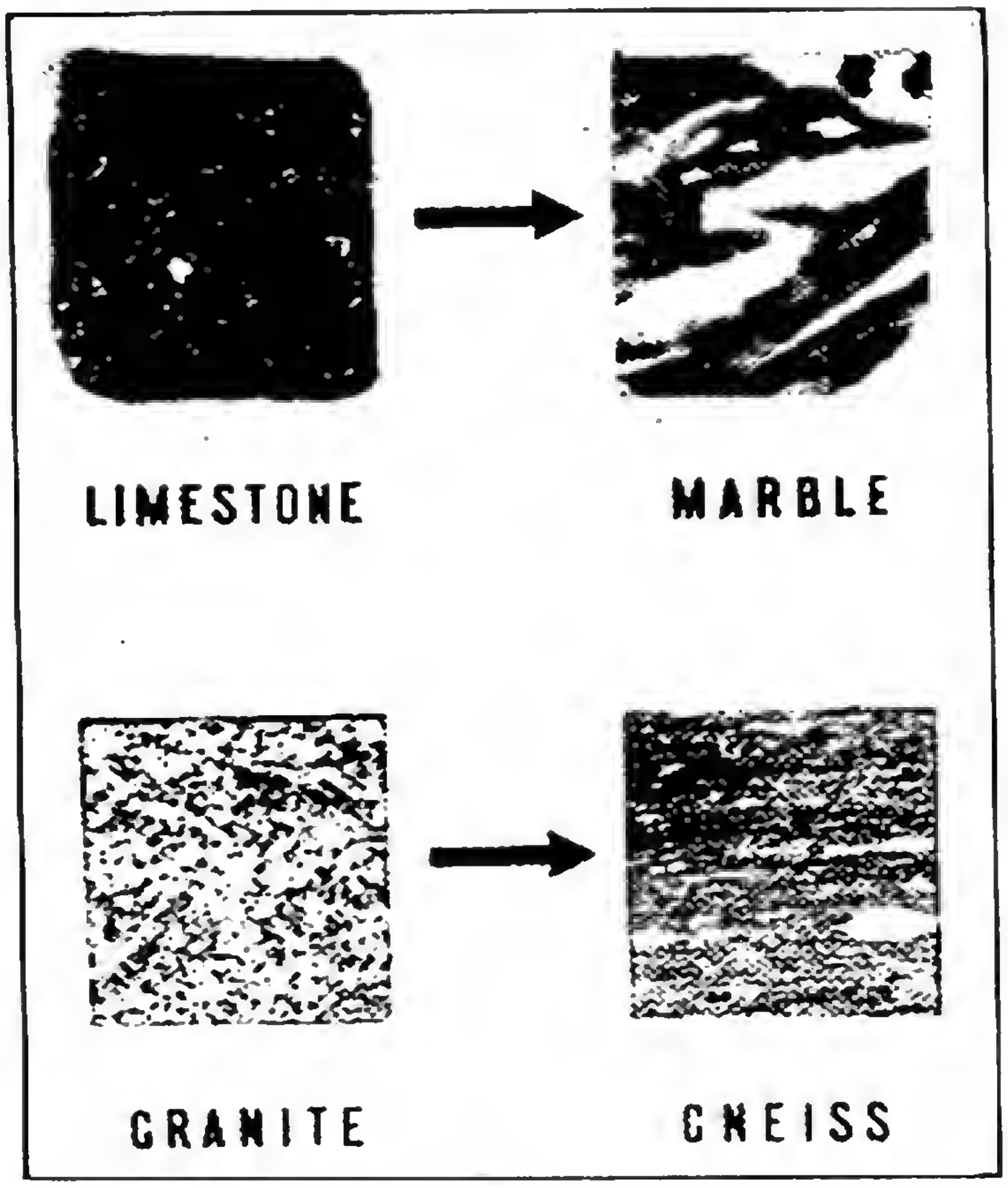


Fig. 11. The right-hand rocks are metamorphic: the kind the left-hand rocks change into when subjected to pressure and heat. The arrows are $1\frac{1}{2}$ inches long. Are all three of the principal types of rocks shown here?

Experiment 1. Collect specimens of rock. Note if possible the basic rock-formation from which they come. Is it a solid mass? Is it in layers? Is it twisted and warped and streaked? Classify the specimens as igneous, sedimentary, or metamorphic. Do this by examining for crystals, granules, or streaks and bands. In the sedimentary rocks, look carefully for the remains of plants and animals that have been turned to stone by the action of water. These are called fossils. They may have been dead for many millions of years.

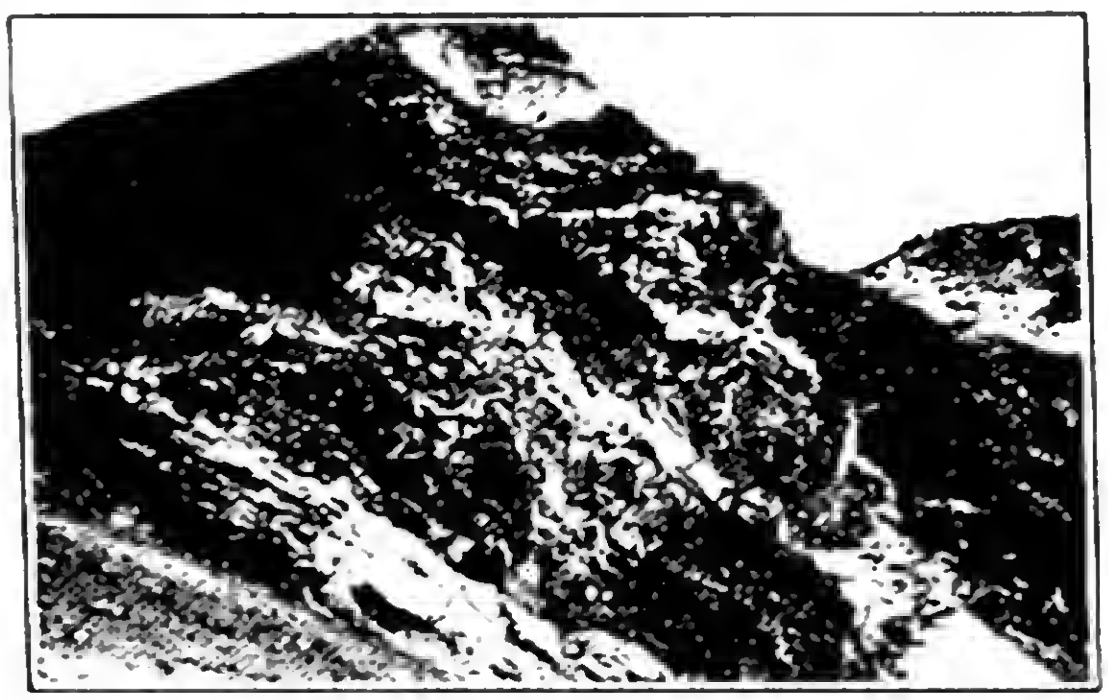


Fig. 12. The streaks and bands showing on the side of this mountain indicate that the rock is metamorphic. What kind of rock was it before the metamorphism occurred, sedimentary or igneous?

EARTHQUAKES

Sometimes the slow forces that move the rocks meet with resistance. Then stresses and strains develop.

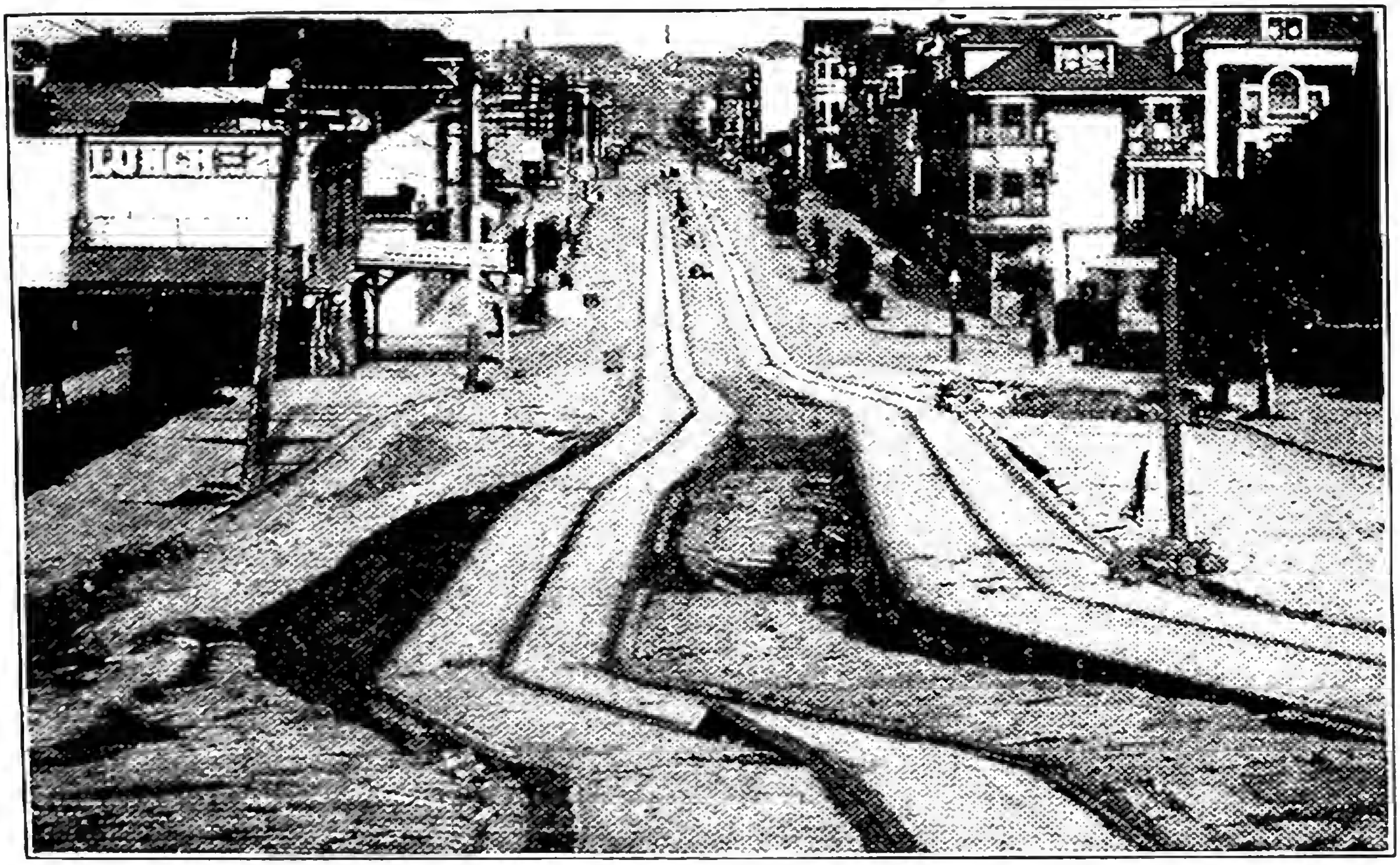
These may accumulate through years and centuries until they become too great for the rocks to stand, and there comes a sudden break or slip in a great section of the Earth's crust. The crack may run for miles, and extend thousands of feet down into the Earth. A whole mountain

Fig. 13. The results of earth-movements. The rock strata have been broken and displaced. Can you tell which stratum on the left goes with each of those on the right?

may move up or down or sidewise for several feet at a single jump. The break will never leave the main crack open, however, as the weight and pressure of the rocks is too great. When the slip comes, it makes such a violent jar that a wave is sent through the solid Earth, just as a ripple on the surface of a pond spreads out from the place where a stone is thrown in. This wave in the Earth's crust is called an earthquake, and it may do much damage to cities and towns in its path. It quickly dies out, however,

and so does not carry its full force very far. It is unusual for an earthquake to do much damage at distances greater than two hundred miles from its source.

All the forces that have changed the surface of the Earth in the past are at work today. Volcanoes are still erupting, and lava flows are still cooling into new igneous rocks.



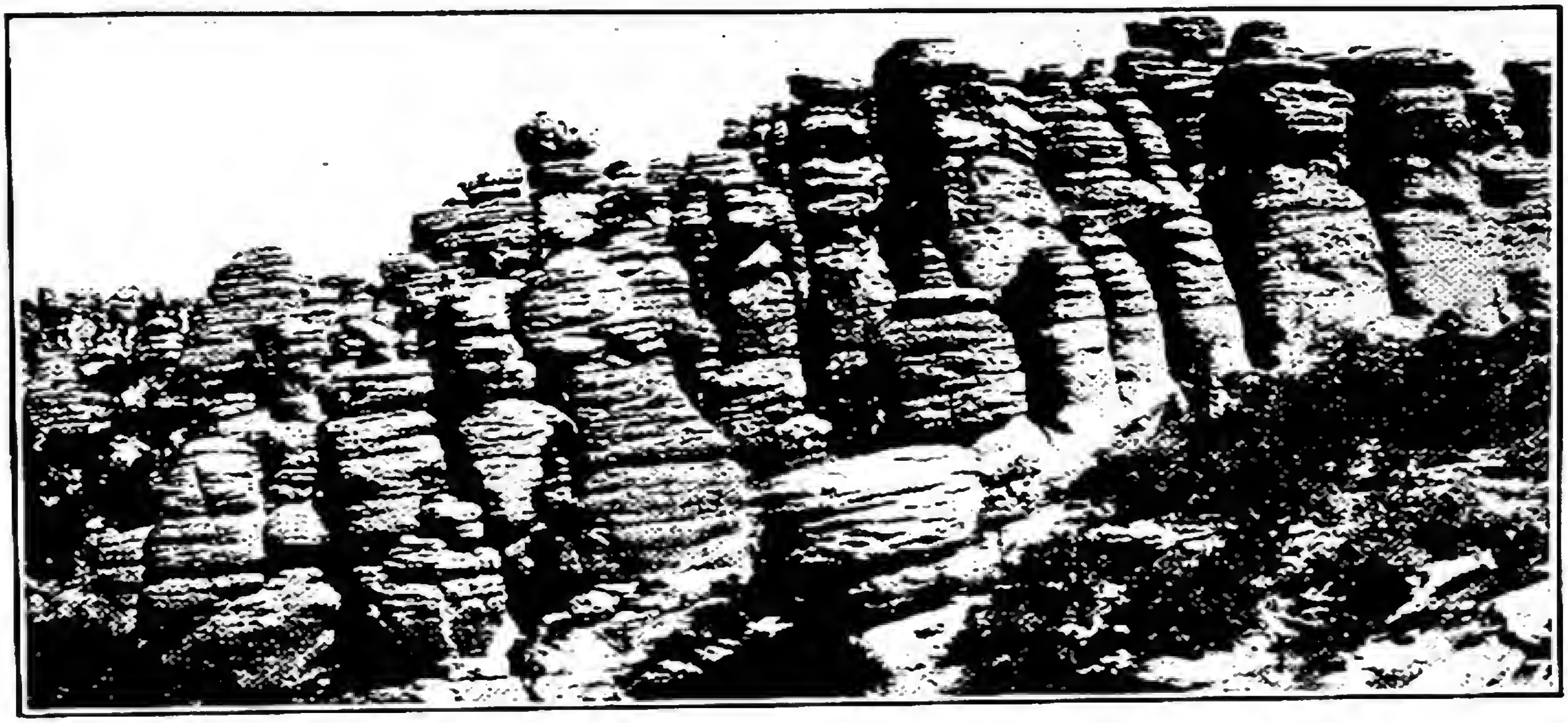
(From the Gardner Collection, Harvard Geological Museum)

Fig. 14. A street in San Francisco after the Earthquake of 1906. Does the condition of the street car tracks give evidence of earth-movement? Note that there are no large open earthquake cracks.

Rivers are still depositing sediments in the ocean. Mountains are still rising, and earthquakes occur somewhere every day. Sedimentary rocks are found on mountaintops, showing that what is now mountain was once ocean. Metamorphic rocks are found on broad plains, showing that what was once mountain is now plain. So the solid Earth is never still. It is only the slowness of its movements that makes us think it is.

The Forces that Wear Away the Land

We have been noticing mainly the forces that build up the land. But it is equally important to consider those which tear it down. Forces are continuously at work which if left alone would reduce the Earth's surface to perfect flatness, so that the land would all disappear and the ocean would cover everything.

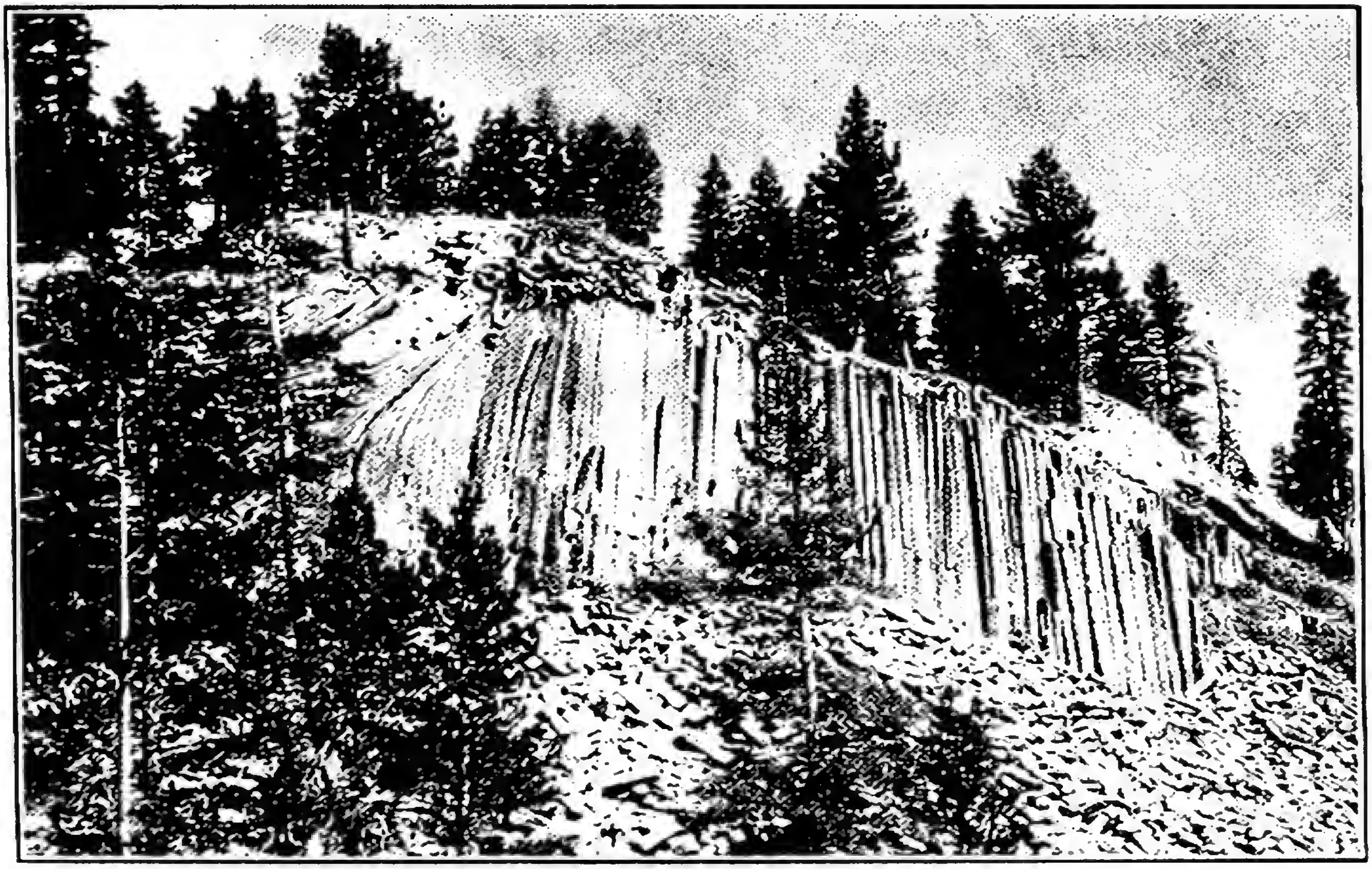


(Photo by U. S. Forest Service)

Fig. 15. These rocks are several hundred feet high. Note the effects of erosion. Rain, wind, and flying particles have torn at them for hundreds of years. Compare this picture with Fig. 9.

Rain washes dust and sand into the streams, and rivers carry these particles down to the sea. Waves beat on the shores of oceans and lakes, and gradually cut away the cliffs, grind them to sand, and carry the sand into the depths of the ocean. Streams and rivers carrying sand and mud in their currents scrape away the soil and rock from their beds and sides. They cut under their banks until these cave in and are carried away too. From time to time floods swiftly carry away great quantities of mud and sand and even solid rocks. In deserts, high winds cause sand-

storms that cut away the rocks. In other places, rain softens whole hillsides, and landslides bring great quantities of earth down into canyons and gorges where streams can carry it away. Sand dunes on deserts and shores are moved slowly about by the wind.



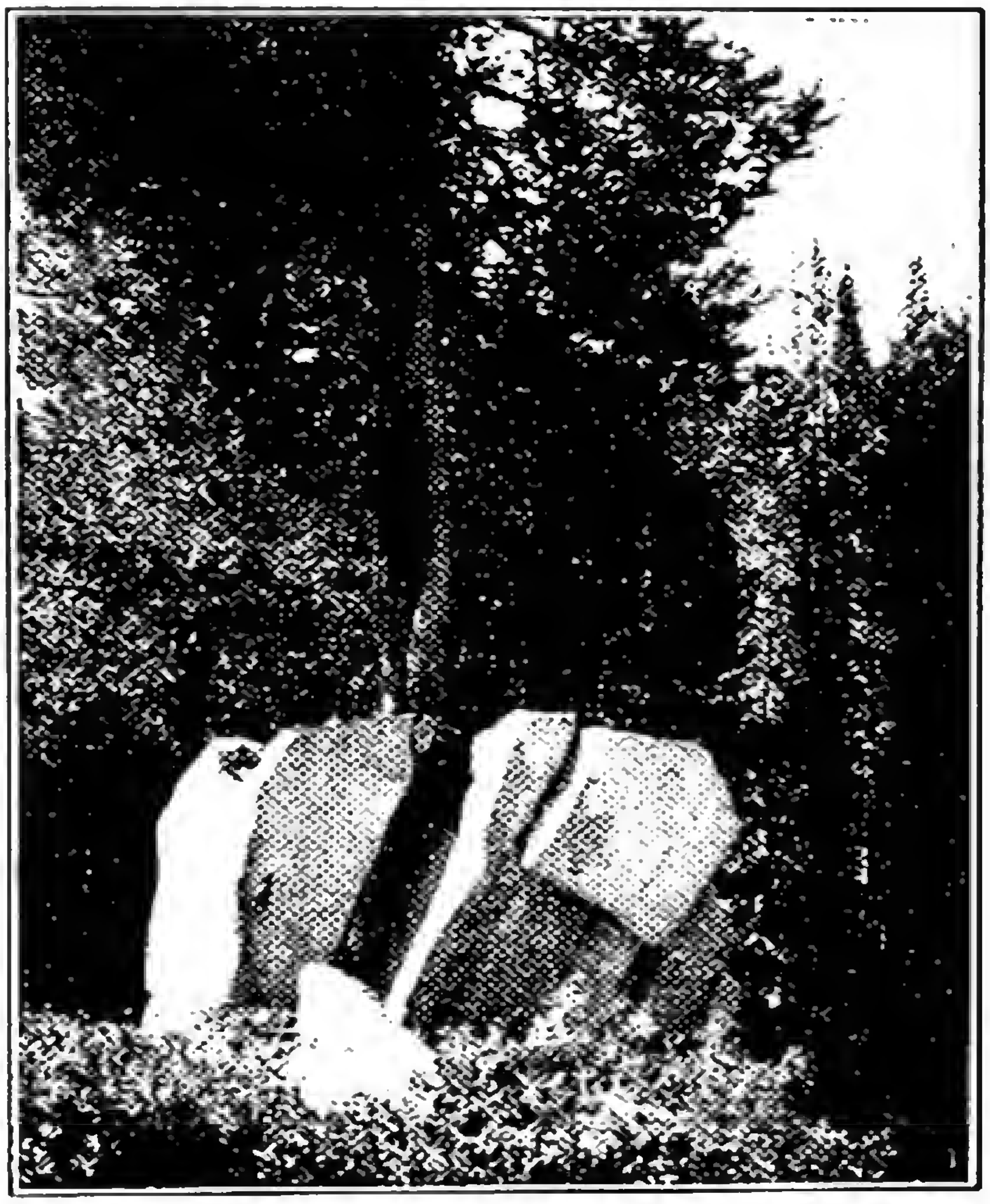
(Photo by U. S. Forest Service)

Fig. 16. The Devil's Post Pile, in Madera County, California. What does it illustrate? Is the rock igneous or sedimentary?

How Rocks are Broken Up

The first step in the wearing away of the Earth's surface is the breaking up of the rocks into sand and soil. This comes about in several ways. Some kinds of rock are more easily affected than others. Wherever we see jagged rocks, straight high cliffs (except on the ocean shore), and deep chasms in the mountains, we may be fairly sure that this is the result of the breaking down or weathering of the rock surfaces. It is the unequal weathering of soft and hard

layers of rock that produces many of these striking effects. The softer layers are eaten away first, leaving the harder layers standing out in fantastic shapes.



(Photo by U. S. Forest Service)

Fig. 17. The trunk of this tree is a foot and a half in diameter, and the granite block it has split is 20 feet across. Do you suppose the rock was already cracked when the tree started its work?

Occasionally, when a major earth-movement occurs, the rubbing and grinding at the place of the major break may reduce considerable quantities of rock material to powder. The contact faces are often smoothed and polished. However, not very many rocks are broken up by this method.

Many rocks contain cracks or joints. Igneous rocks contract when they cool from the original molten state, and in so doing they become shot through with many regular vertical joints. Such rock masses often look like posts packed tightly together. Sedimentary rocks are often jointed, too, but in this case the cause lies in the mechanical strains developed when the sediments were uplifted from the ocean bed.

Rocks are broken up by freezing water. When water freezes, the resulting ice takes up more room than the water did. The expansive force developed in freezing water is really enormous. Water seeps into cracks and joints in the rocks, and when it freezes it forces open these cracks and breaks the rocks apart. Sometimes it breaks off small pieces, and sometimes it freezes in large cracks and breaks off huge boulders.

Rocks are often broken apart by the growth of plants. Tree roots start in small cracks, and as the tree grows the root widens the cracks until a break occurs. Grasses and shrubs repeat the process on a smaller scale.

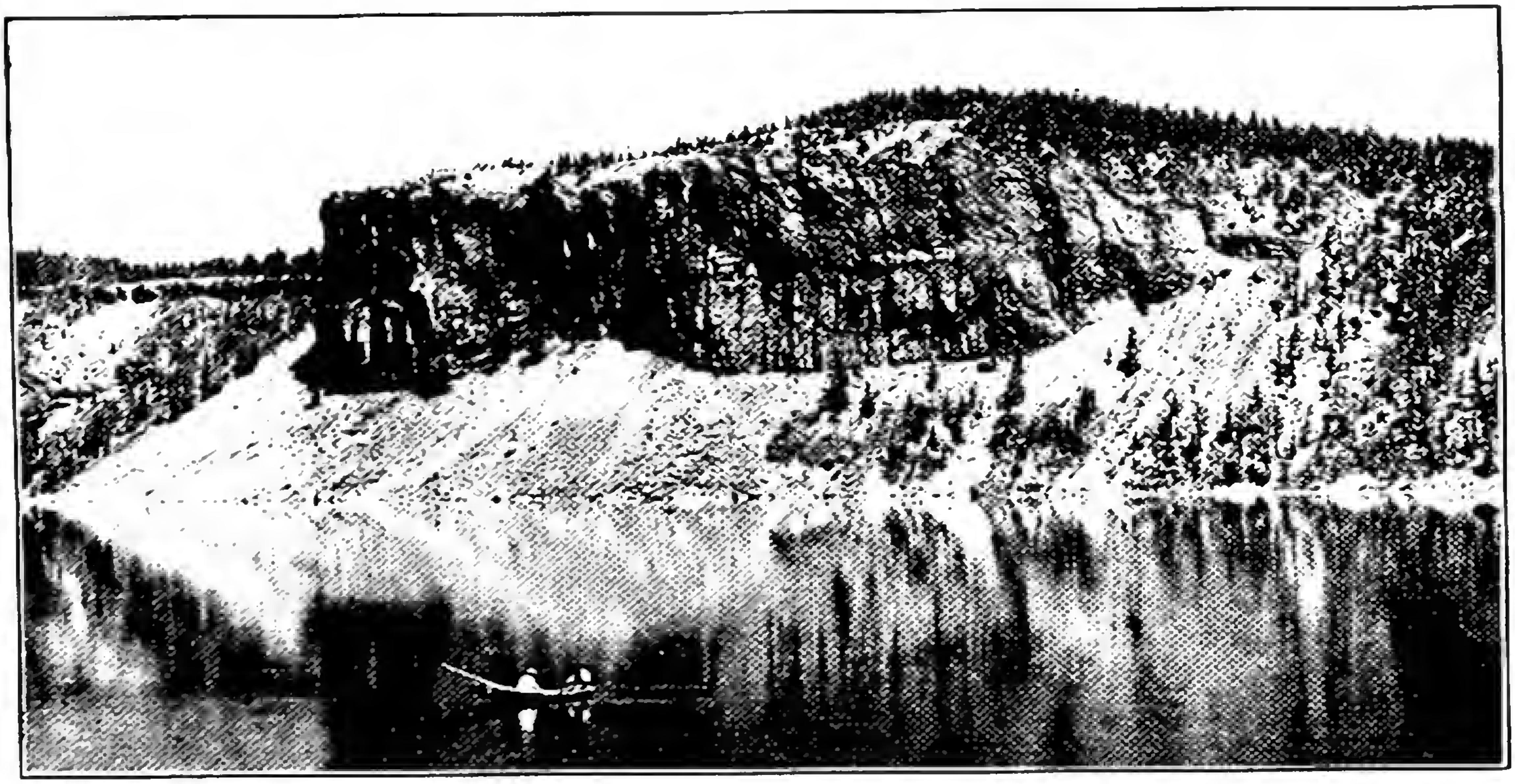


Fig. 18. On the far side of the lake is a talus slope. The figures in the foreground give some idea of the size of the slope. What do you conclude from the fact that trees are growing on the slope? Why are there so few trees on the slope directly below the high sheer cliff?

When weathering of these types occurs on a mountain-side, the fragments fall down to the bottom of the hill, forming a sloping heap against its side. This material is known as talus. As more and more talus accumulates at the foot of the mountain, slides occur from time to time which reduce the slope. These landslides and rock slides are small as a rule, but occasionally a very large one occurs, moving whole acres of material.

Experiment 2. Soak a piece of sandstone in water overnight. Then pack it in "dry ice" and let it freeze for an hour or two. When the "dry ice" has evaporated, heat the stone over a gas or alcohol flame. Observe what happens at each stage.

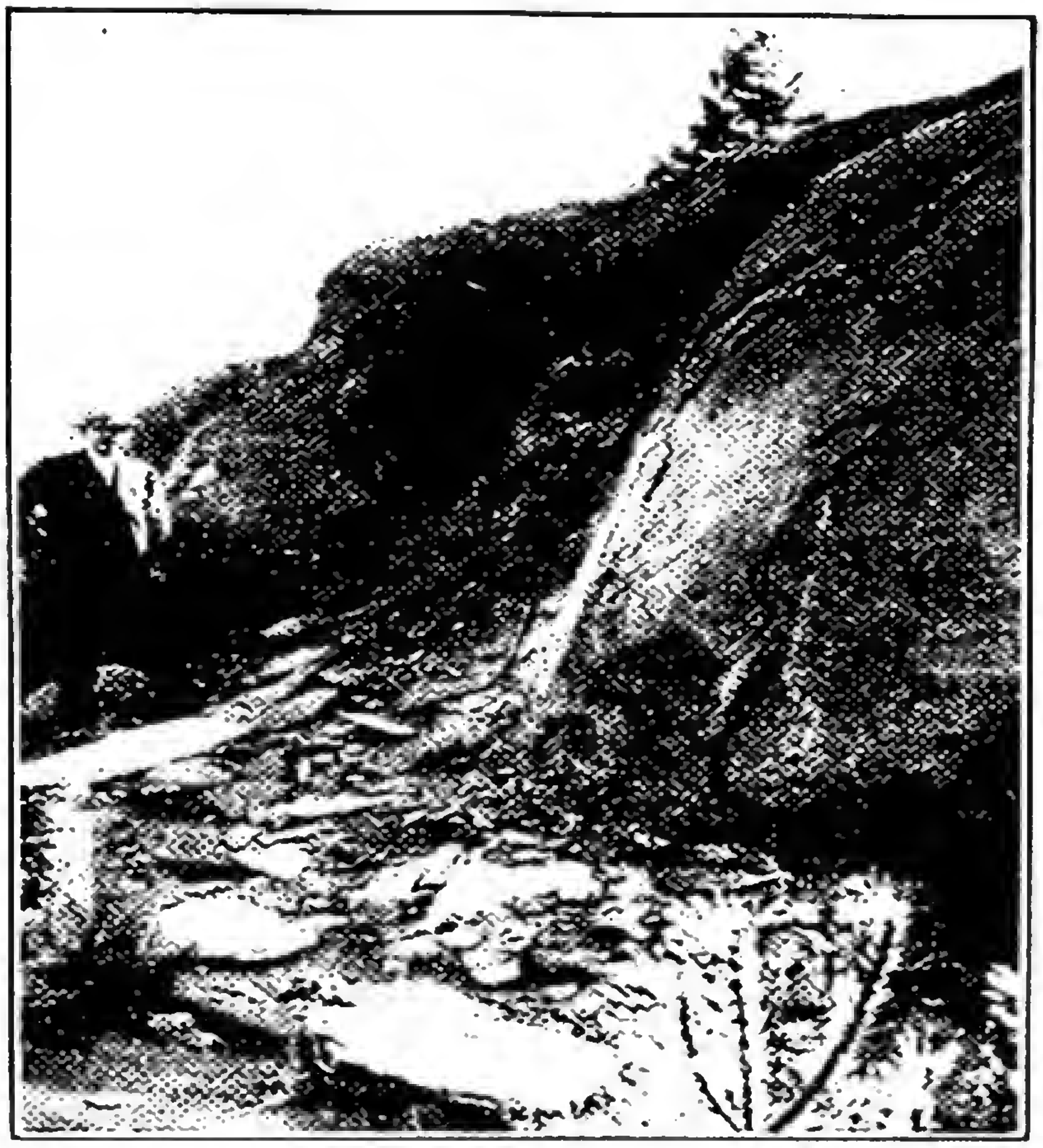


Fig. 19. The chips lying on the ground have flaked off the large rock at the right. Notice the scaly appearance of the large rock, and its rounded shape.

Experiment 3. Heat a piece of granite or basalt over a gas or alcohol flame. Then dip it in a pan of cold water and observe what happens to it.

Rocks expand when heated and contract again when they are cooled. But rock is a poor conductor of heat, so the outside may get very hot while the rock remains cool a few inches—or even a fraction of an inch—below the surface. On a warm day the outer layers then tend to buckle and loosen themselves from the body of the rock. At night the surface cools down rapidly until its temperature

(From the Gardner Collection, Harvard Geological Museum)

Fig. 20. This sandstone has crumbled so that it is difficult to recognize it as a stratified rock. The rock has been exposed for some time on the side of a hill. The area shown is about five feet from top to bottom.

is lower than that of the interior. The outer shell is now too small, and it breaks apart and falls off. Sharp edges and corners are destroyed most rapidly by this means, so that a rock which is much weathered by heating and cooling comes to have a rounded appearance, with a rough, scaly surface.

(Courtesy U. S. Bureau of Chemistry and Soils)

Fig. 21. The side of a cut made down through the soil. Each joint of the ruler is 6 inches long. The dark surface is humus soil. The lighter layer just below it is sandy loam. The second dark layer is a mixture of fine and coarse particles, and at the bottom is a compact layer of clay. In which layer will the largest amount of decayed organic material be found? In which the least?

The Formation of Soils

The types of weathering described above often go on together. Heating and cooling of the rock itself may flake off small chips, but more often this process develops cracks into which water seeps, completing the process when it freezes. Water also soaks directly into porous sandstones and limestones, causing them to crumble to pieces when the water freezes.

After the rock has been broken into smaller and smaller fragments it becomes gravel or sand and then finally a part of the soil. Soil consists of small fragments of rock mixed with the products of the decay of plants and animals. If one digs down into soil which has remained in the same place where it was formed, the fine surface material gives way after a few feet to coarser particles containing smaller amounts of decayed organic material. The particles become larger and the organic materials scarcer, until finally the solid rock, or bed-rock, is reached.

Thus we have seen that the mountains which are uplifted by earth-movements are the source of the soil, which is washed away finally to the ocean and deposited as sediment. The sediment becomes rock again on the ocean bottom, and finally another earth-movement lifts it high above the sea. The process is endless. Nothing really endures.

Questions for Review, Discussion, and Study

CHAPTER I

1. Do you suppose our Sun is much hotter than the other stars? Does it feel hotter to us? Why?
2. Until recently, only eight planets were known. What is the name of the ninth? How recently was it discovered? By whom?
3. Does our Earth have more moons than any other planet? Does it have fewer?
4. Is our Earth the largest planet? The smallest?
5. How can you tell, at night, whether you are looking at a star or at a planet?
6. Do you suppose that the ground you walk on when you come to school was once a part of the Sun?
7. Do you suppose that there is still any of the "star dust" mentioned in the second theory of earth formation?
8. What does gravity have to do with our notion of "up" and "down?"
9. What might be the path of a particle of water, starting from the ocean near Boston, and following the "water cycle?"
10. Can you be pretty sure that water was already present on the Earth when life first appeared?
11. Why does the Earth seem to be mostly soil, when it is really mostly rock?
12. What are three of the differences between basalt and granite?
13. Why are sedimentary rocks present only very near the surface of the earth?
14. What part does water play in the making of rocks?
15. If you know how high a mountain is, and how fast it is being pushed up from the interior of the Earth, why can't you just use arithmetic and tell how long the mountain has been rising?

16. If you saw some marble and didn't know it by name, could you still tell that it was a metamorphic rock? How?

17. Do you suppose the soil in your garden is really made up of rock particles, like very fine sand?

18. What evidences have you ever seen of the expansive force of freezing water?

19. Water always expands when it freezes. What would happen if the water became very cold, but was enclosed in something that kept it from expanding?

20. What evidence have you for believing that brittle things may break if cooled very rapidly?

21. If you were digging a very, very deep well in your own back yard, do you suppose you would finally come to hard, solid rock?

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CHAPTER II

THE FORCES THAT WEAR AWAY THE LAND

Chemical Decomposition of Rock

We have seen how the land is built up, and we have seen something of the forces that tear it down again. These two activities always go on together. For a while we shall notice some of the ways in which the land is torn down and transported to the sea, but through it all from time to time we shall see upbuilding forces working at the same time as those which tear down.

In fine, porous rocks, water is absorbed in considerable quantities. It seeps long distances in such material, going uphill as well as downhill to wet the dry areas. The force which draws the water along is called capillarity or capillary attraction.

Experiment 4. Heat several pieces of glass tubing over a bunsen burner or alcohol lamp and draw them out thin. Cut off sections 5 or 6 inches long from each of these as soon as it is cool. Dip each one in water. The smaller the tube the higher the water will rise in it. The reason for this is that water tends to wet and spread over the surfaces with which it comes in contact. If one tube is half the diameter of another, it will have one half the surface and hence one half the attractive power of the larger tube. But the column of water will have only one fourth the weight of the larger column, and it will therefore rise twice as high in the smaller tube.

The water, coming in contact with rock surfaces, slowly dissolves them. If the water is pure the process is very slow, but if it is slightly acid the process is far faster. The commonest acid in natural water is carbonic acid, formed by the solution of carbon dioxide from the air or from decaying vegetable matter in the soil. Water containing this acid dissolves many rocks, particularly limestone and marble, with considerable rapidity. The action is uneven,

some parts of the rock being eaten away while others remain. Many porous and pitted rocks are the results of such action.

(Courtesy U. S. Bureau of Chemistry and Soils)

Fig. 22. A six-inch layer of soil lying upon the rock from which it was derived. Could plants with very long roots grow here? What difficulties would a farmer in such a region encounter?

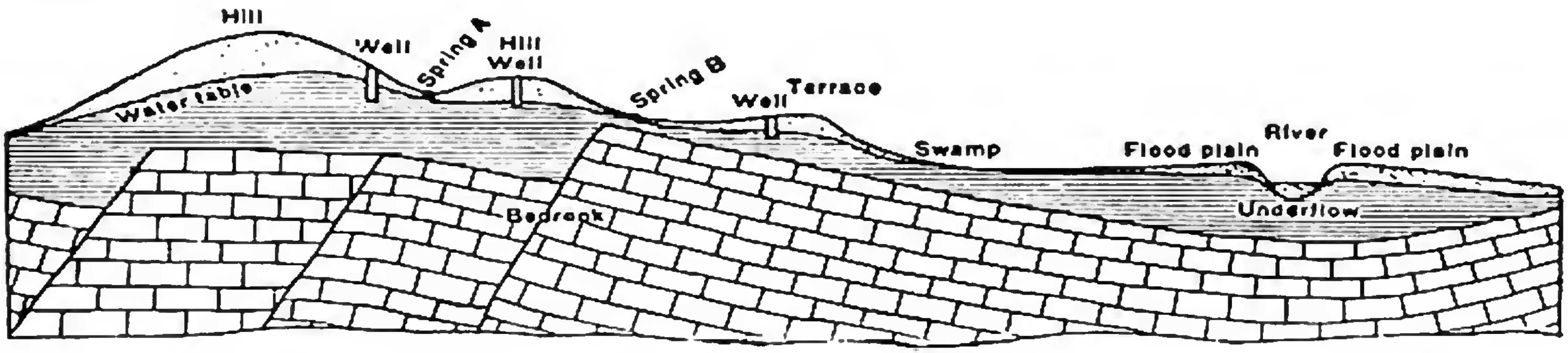
Experiment 5. Drop a piece of limestone or marble in dilute hydrochloric acid. Note how it is dissolved. After it is about half gone, pour off the acid, wash it, and examine its surface.

Experiment 6. Weigh a piece of dry porous sandstone. Then put it in water and let it stand for at least a day. Remove it, wipe off the loose water on the surface, and weigh it again.

Water in the Ground

There is water in the ground almost everywhere. A great part of all that descends in rain sinks into the earth. It seeps down slowly until it fills all the spaces in the soil, and it penetrates the cracks and joints in the rock. Many rocks, such as the sandstones, are porous. Water soaks into and through these until they are filled like sponges. Even the hardest rocks have some pores, and in time these too are filled. The water in the ground goes down to the place where, because the pressure of the overlying rocks is so great, no more cracks exist. This depth varies, according to the nature of the rock, from half a mile to ten miles below the surface of the earth. Beneath this depth the rocks contain no water.

Just above this depth, the rocks are filled with as much water as they can hold; that is, they are saturated. On the surface of the Earth, as well as below the surface, many places are found where the ground is not saturated with water; cracks and pores exist which are not filled. But always if we go deep enough, we find saturated rock. The level beneath which the earth is saturated and above which it is not, is called the water table. The depth of the water table varies from zero in marshes and swamps to a thousand



(Courtesy American Museum of Natural History, New York)

Fig. 23. This cross-section diagram shows how the water table may vary in different localities. Notice the places where the water table has zero depth.

feet or more in other places. It is usually farther below the surface on the tops of hills than in valleys. Gravity tends to lower it to the same level everywhere, but the movement is very slow—a fifth of a mile a year in coarse sandstone, for example. Since the hills usually receive as much or more rainfall than the valleys, the water table is uneven in hilly regions, but as a rule this unevenness is less than that of the surface. Sometimes the water table comes to within a few feet of the surface, so that it is above the beds of the streams in the region. These streams are therefore permanent, and do not dry up as soon as the rain and snow in the mountains are gone.

Springs and Wells

Often a relatively non-porous layer overlies a porous layer. If these layers lie at an angle, with the porous layer

coming to the surface at its upper end, water absorbed into it will flow down under the non-porous or impervious layer. The pressure of the water above will tend to raise the water table up into the overlying layer, but this is difficult or impossible. If there is a crack in this impervious layer, or if it ends below on a hillside, a spring will appear. If a well is drilled down through the impervious layer, the water from the underlying layer may by its own pressure rise and overflow at the surface of the ground. This type of well is called an artesian well. The term artesian was at first applied only to wells which actually overflowed, but at the present time it is applied to any well in which the water-bearing layer is beneath an impervious layer. Artesian water is usually safer for drinking purposes than the water from shallow wells drilled in the soil above the impervious layer, in regions where such a layer exists. This artesian water has filtered for long distances through the porous layer, and it is therefore less likely to be contaminated than is the water from the shallow wells.

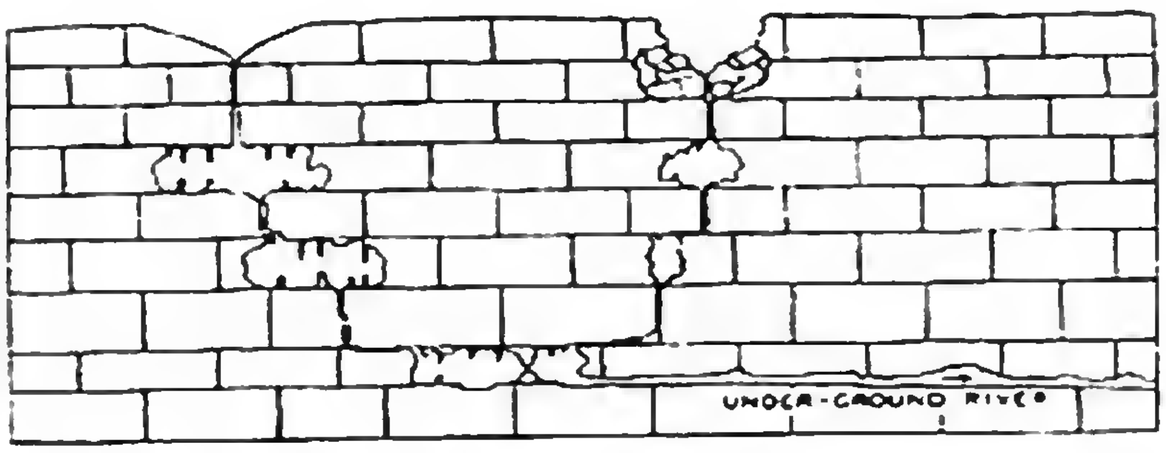
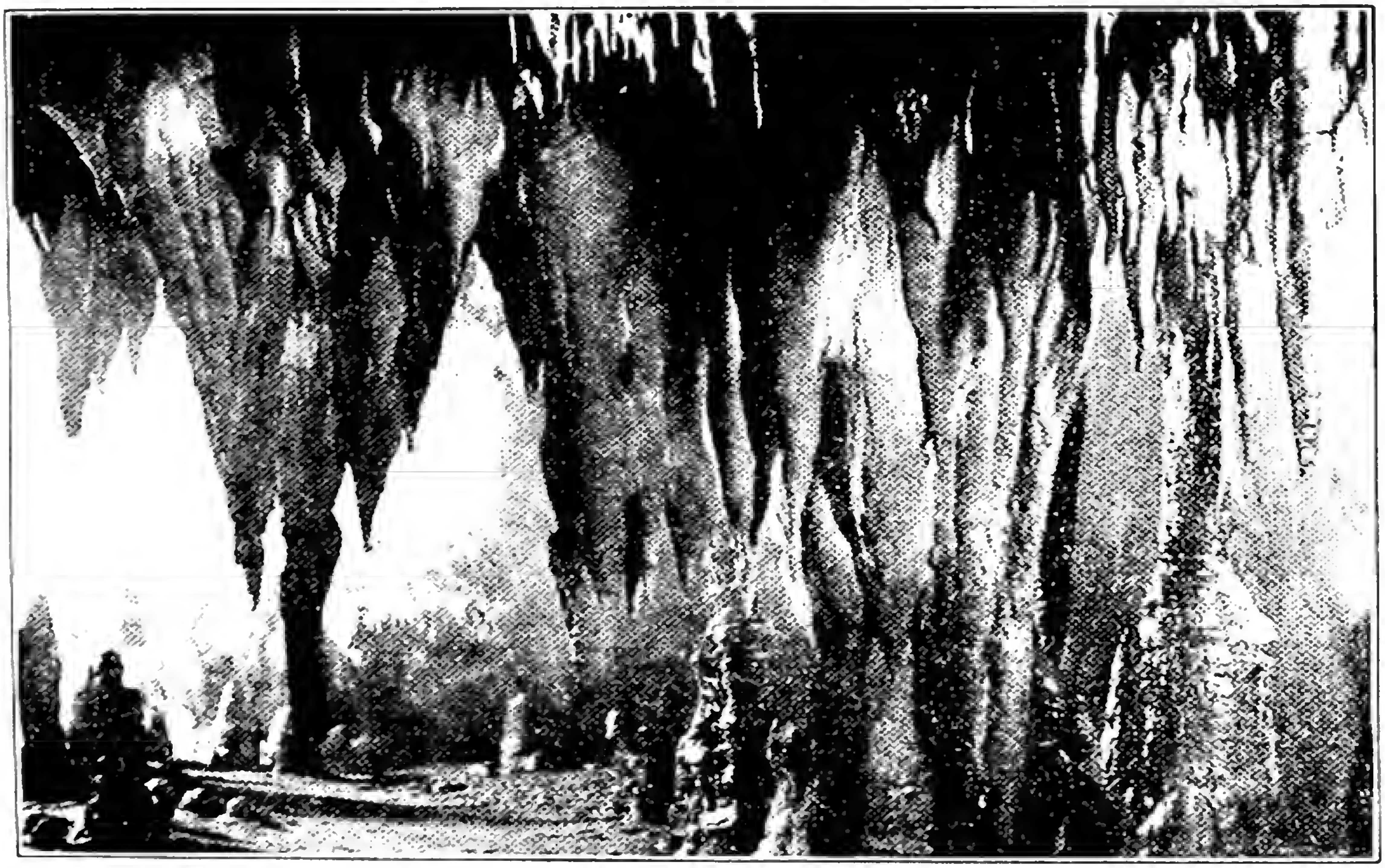


Fig. 24. This diagram shows how water may dissolve portions of a limestone formation, leaving holes in the ground and caves underground. What has happened to the right-hand hole near the surface? Are any pillars shown in the diagram?

Underground Caves

When acid-bearing water seeps into a limestone formation, the limestone is eaten slowly away. Caves and underground streams develop. These streams in time may become very large. They may even drain away the water and lower the water table in some regions, to such an extent that the dissolving action of the water virtually ceases in those regions. Large holes often lead from the surface of the ground down into these caverns. Later, water

carrying much lime in solution may seep down into an empty cave and collect in drops on the ceiling. As this water evaporates, it will leave a deposit of lime. The drops may fall to the floor and as they evaporate leave further deposits there. In the course of years and centuries these deposits are built up until they look like rock icicles. Finally the one built down from the ceiling may join with



(From the Gardner Collection, Harvard Geological Museum)

Fig. 25. "Rock icicles" in a limestone cave. Does their appearance give any evidence of the manner in which they were formed? What part has evaporation played in their formation?

the one built up from the floor, forming a pillar. Other deposits may take various odd and fantastic shapes, giving a weird beauty to the cavern.

Glaciers and their Work

Periods of colder and warmer climate have followed one another ever since the Earth had a solid crust to keep in

the heat of the interior. Thousands of years ago there was a period when the surface of the Earth was much cooler

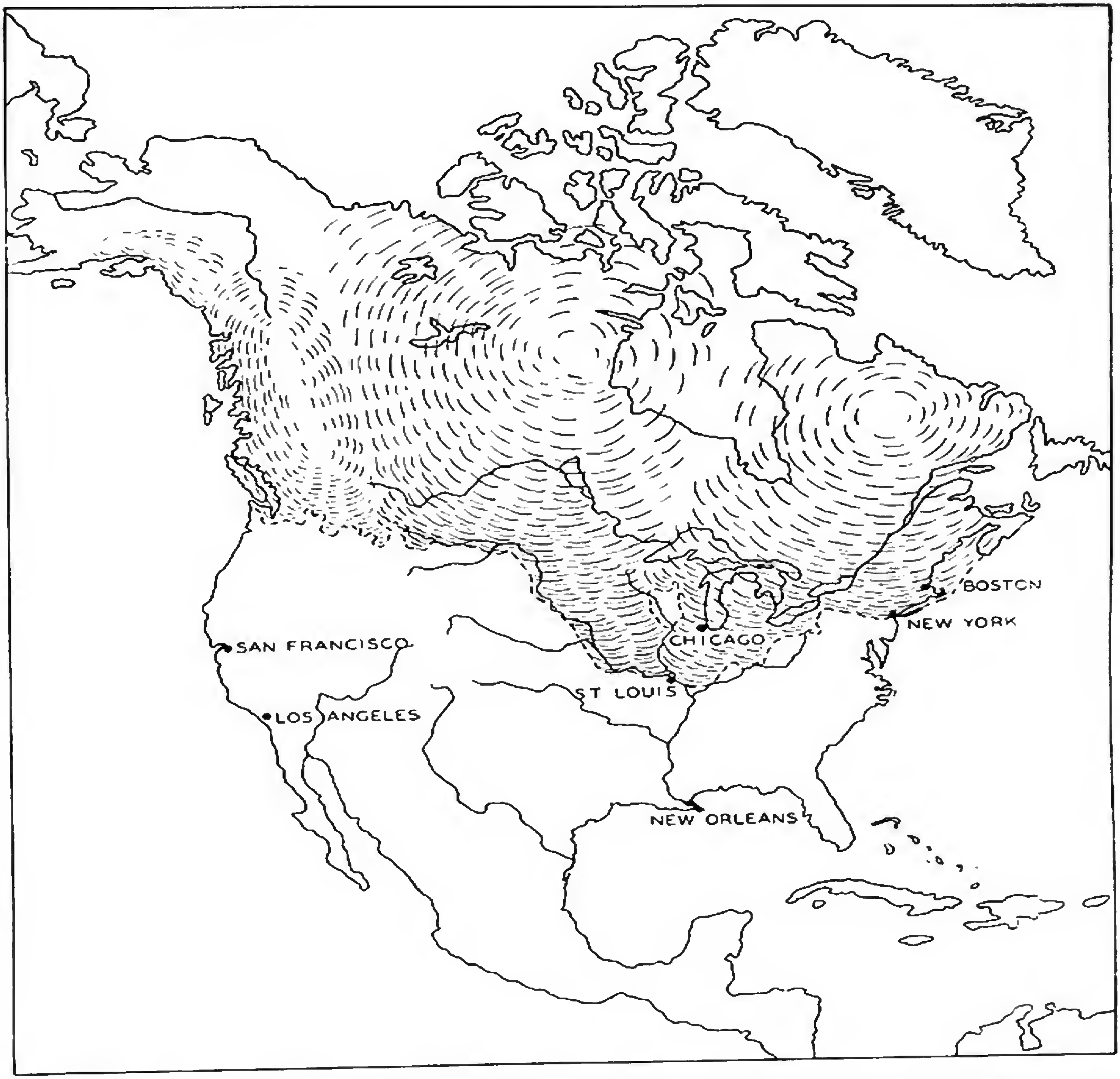
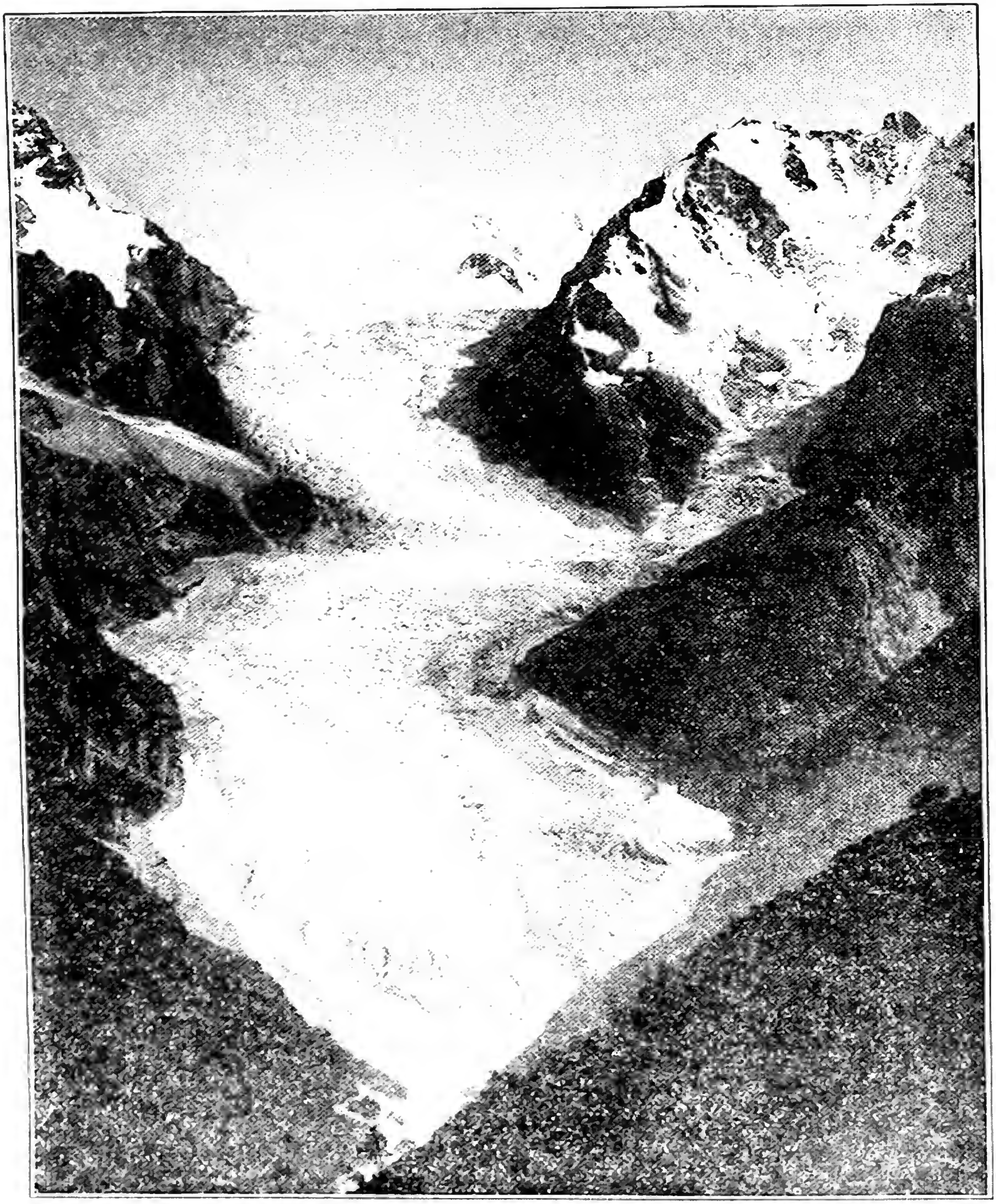


Fig. 26. This map of North America shows how far south the great glacial ice-sheets extended. The regions affected by this ice still show the results of its work.

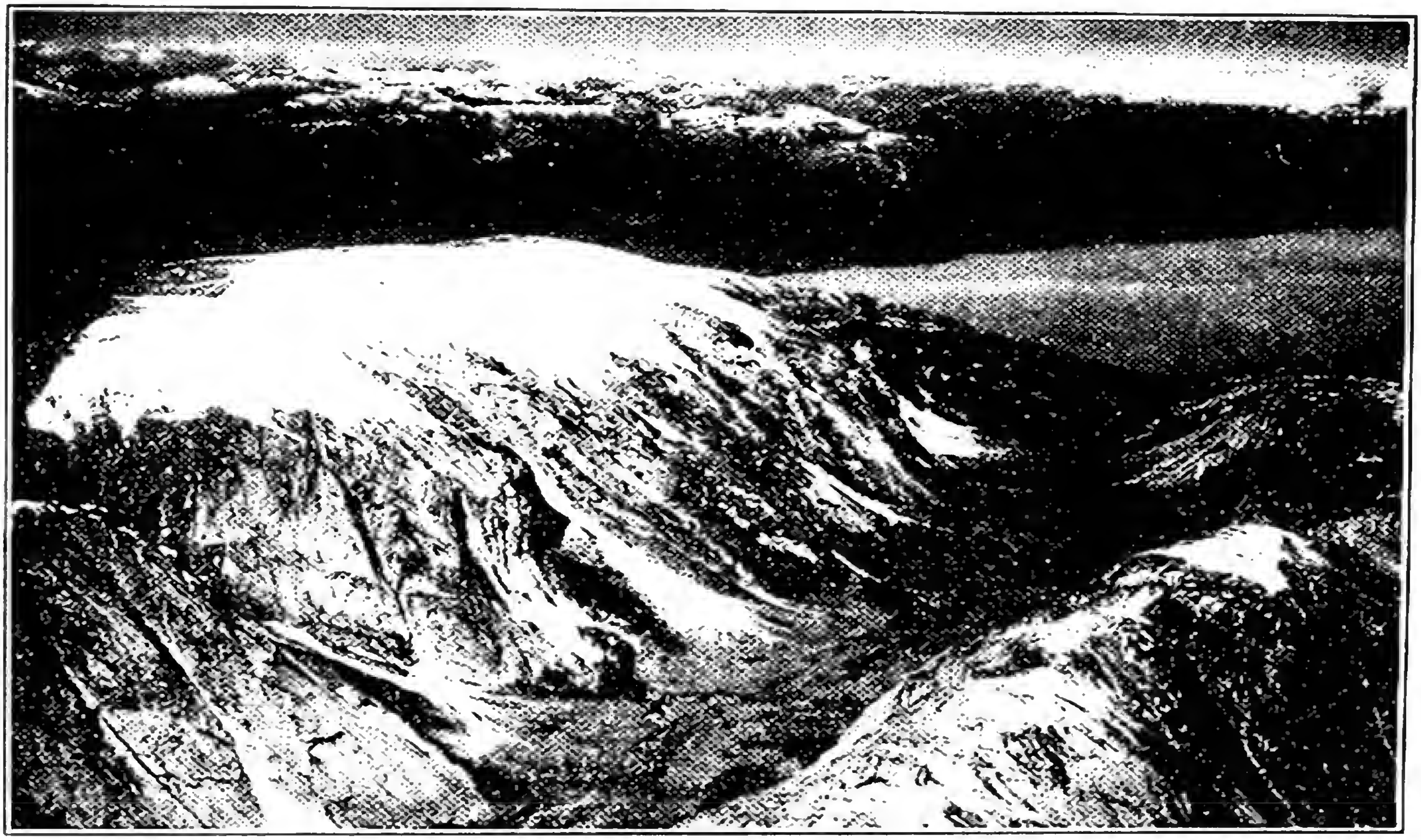
than it is now. At the time of which we are speaking, more than twenty thousand years ago, great ice-sheets covered large portions of North America and Europe, just as they



(From the Gardner Collection, Harvard Geological Museum)

Fig. 27. A valley glacier. Notice the snow-field at the upper right. Is there a tributary glacier here? Are any moraines visible? What causes the darker streaks in the ice?

cover Greenland and the Antarctic Continent today. As the ice layer grew thicker and thicker from the accumulation of snow, it began to move, spreading like heavy tar,



(Photo by U. S. Forest Service)

Fig. 28. This airplane view of a valley shows the rounded appearance typical of glaciated regions. By comparing this view with that shown in Fig. 49, can you be reasonably sure you could recognize glaciated country?

but much more slowly. It flowed outward and downward until it reached the ocean, or some region of warmer climate, where it melted. As it moved it picked up loose rocks and even tore away solid ledges from hillsides, carrying them along as it went, and grinding, scratching, and scouring the surface beneath. When it melted, it deposited these rocks and bowlders in heaps at its edges.

Glaciers exist today in small valleys in high mountain ranges. Snow may accumulate at the head of such a valley until its weight turns the bottom parts to ice and the whole mass creeps down the valley. At the beginning of the mo-

tion, a great open crack or chasm often appears between the hillside and the ice. As the glacier grinds along, it picks up loose materials in its path. It does not advance evenly. The center moves faster than the sides, and the top moves faster than the bottom, just as is the case with rivers. The movement is rather slow: from a few inches to fifty or sixty feet a day. Large and small cracks develop in the ice as it moves, making the upper surface irregular in spots. Sometimes great open chasms appear when the glacier moves over uneven ground.

(Photo by U. S. Forest Service)

Fig. 29. In the center of this airplane view is a hanging valley. Is its shape characteristic of glaciated country? Where has there been a tributary glacier?

The amount of material picked up and carried by glaciers is very large. Their scraping action is very strong, and glacial valleys become rounded at the bottom, or U-shaped, in contrast to the V-shaped river valleys. Large glaciers scrape out the bottoms of their channels more rapidly than do small ones, so that the bottom of a large glacier will be considerably lower or deeper than the channels of smaller ones flowing into it. The result is that when the ice melts out of all the channels, we see "hanging valleys" where the smaller, shallower valleys end with their bottoms high up on the sides of the main valley.

When a glacier melts, it deposits the material it has been carrying. Streams issue from under it at the end, spreading loose stones and rubbish over the landscape. The piles of loose material dropped by melting glaciers are called moraines. Many of the hills of the eastern United States

are moraines left by the melting of the great ice sheet.

Glaciers transport soil from the highlands to the lowlands. The deposits at the end of melting glaciers are composed of large bowlders, small stones, pebbles, sand, and fine clay, all mixed together. Glacial soil is fertile, but it is usually difficult to work on account of the stones it contains.

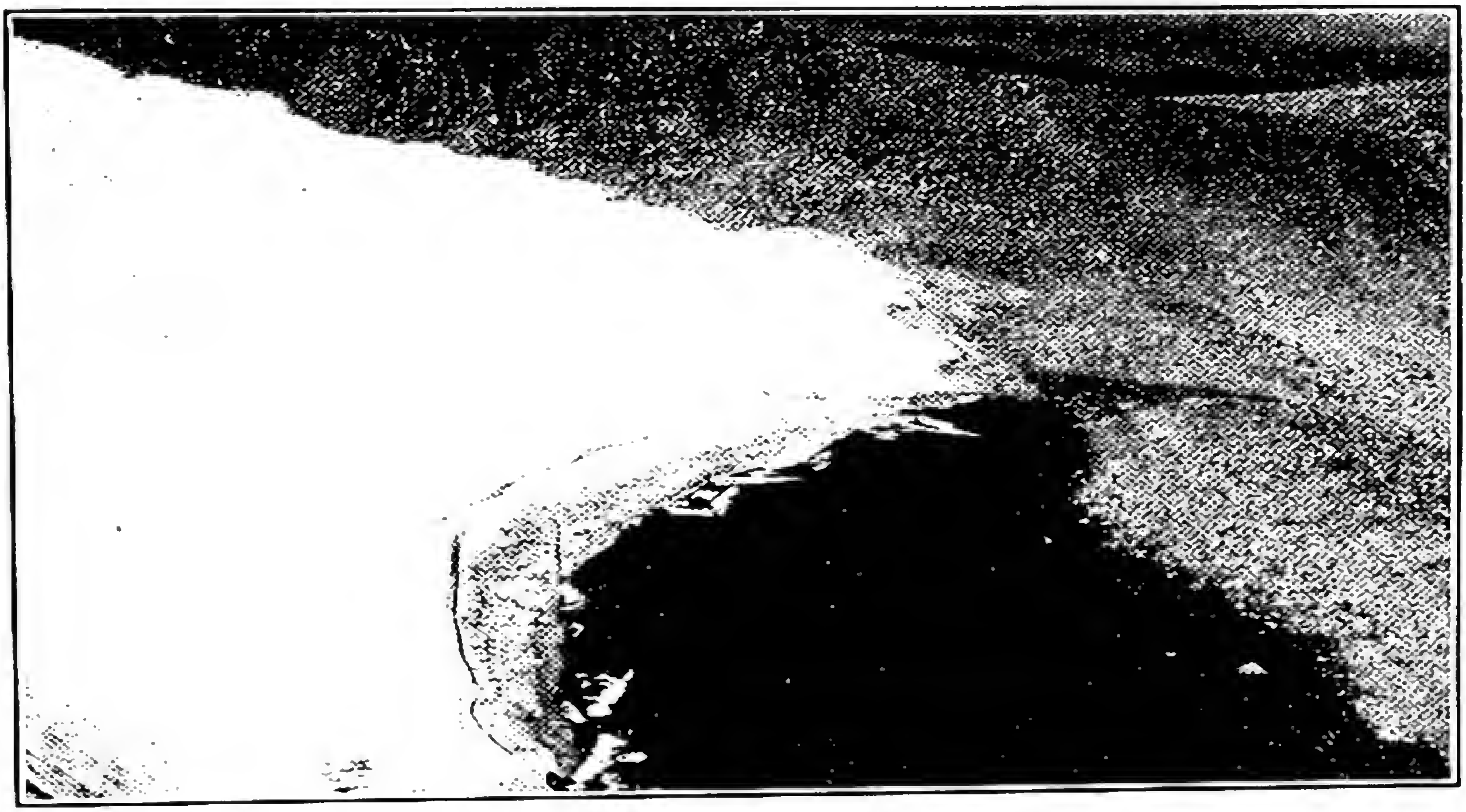


Fig. 30. Small icebergs breaking away from the lower end of a glacier, where a glacial dam, shown at the right, has formed a lake basin. How were the broken fragments of rock collected and piled to make this dam?

When a glacier reaches as far as the ocean, the warm ocean water melts the ice at the foot of the glacier. If the glacier moves so fast that the ocean water cannot melt the ice as fast as it advances, great chunks of ice break off and drift away. These chunks are called icebergs, and they are often many times larger than the largest ships. Only one eleventh of an iceberg is above the surface of the water as it floats, but even this part of the berg may be as big as a small hill. Sometimes icebergs drift clear into the temperate zones before they melt.

From time to time a ship runs into an iceberg in the dark or in a fog, and is wrecked. Since 1912, when a large trans-atlantic liner was wrecked by collision with an iceberg and many lives lost, the United States Coast Guard has maintained an ice patrol to warn ships of the presence of large bergs. During the dangerous months of every year, patrol boats cruise about in the iceberg zones and send out radio messages which all ships may hear, and so learn the positions of the icebergs.

THE WIND AND ITS WORK

We do not often think of the wind as one of the forces that wear away the land, yet it is. It blows fine particles of dust and sand about, and these usually come to rest at points lower than those at which they were picked up. Often the dust is blown into streams, lakes, or oceans, where it settles to the bottom of the water.

Sometimes the wind blows with great force. On high mountain tops, at the mouths of canyons, and on the seashore, trees can often be seen which have been bent and whose branches have been twisted by the force of the wind. Occasionally tornadoes sweep across the

(Courtesy U. S. Bureau of Chemistry and Soils)

Fig. 31. This cross-section view shows glacial soil to a depth of about eight feet. The trees in the top of the picture are in the distance. Two boulders are shown near the bottom. What evidence of another boulder remains near the surface?

interior plains, leaving death and destruction in their paths. Sandstorms on deserts are feared very greatly by travelers and dwellers in such regions. The sand cuts away the bases of trees and telephone poles, scratching windows, and in the course of centuries wears away rocks and even whole mountains. Curious rock formations are often found in deserts where a hard rock overlies a soft one, and the sand cuts away the lower layers faster than it does the upper ones.

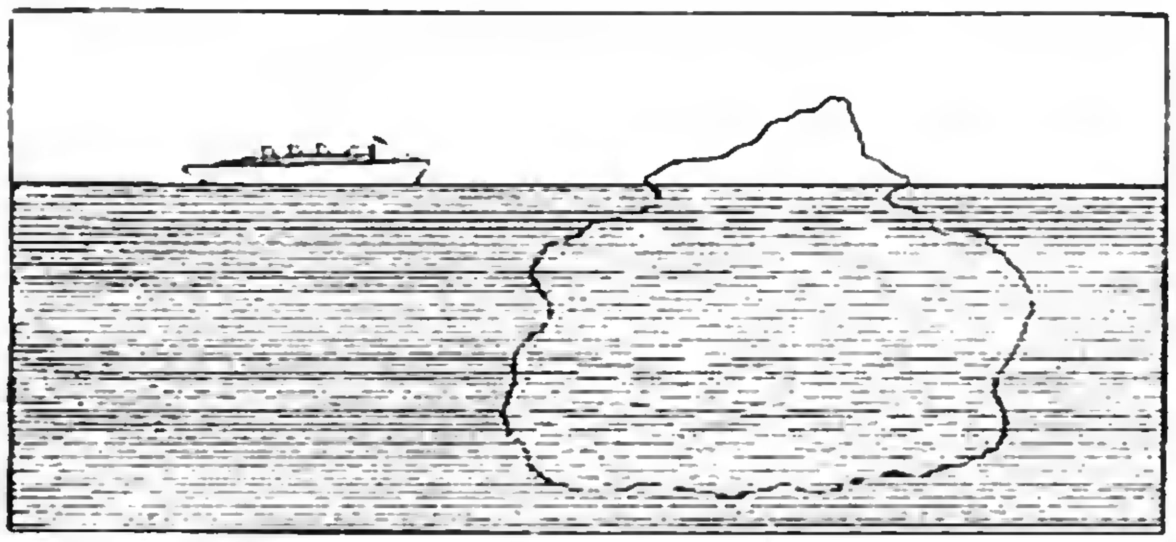


Fig. 32. When an iceberg appears to be as large as a ship, it is really vastly larger. How do you account for the fact that the berg is smaller just below the surface of the water than it is at the surface?

In many deserts and on the shores of oceans or large lakes the sand is heaped up in piles or dunes. Sand dunes often move slowly over the land, a hundred feet or so a year, as the prevailing winds blow the sand on one side over the top and let it roll down the other side and come to rest. These dunes have been known to bury houses, forests, and whole villages, uncovering them again years later as they pass on. When a dune becomes overgrown with grass, it may resist further movement and become stationary.

(Photo by U. S. Forest Service)

Fig. 33. What has caused this tree to grow in this fashion?

Sometimes the wind sweeping over grassy plains comes to a place where the soil is loose and little vegetation is growing. It may blow away the soil at this point, leaving a hole several feet deep.

The Ocean

When a mountainous region near the seashore is lowered by earth-movements, a very ragged and cut-up shore line results. Long, narrow bays appear where formerly there were valleys. Old mountains become islands and peninsulas. If, on the other hand, elevation takes place along a shore line, a low flat coastal plain is the result.

(Courtesy R. A. Daly)

Fig. 34. This rock has been worn by wind and wind-driven particles. How can you tell that its present shape was not brought about by glacial action?

Wherever the land enters the sea at a fairly steep angle, the waves cut the rock and soil away. The sand is washed out until it gets below the level of surface currents, where it comes to rest. The waves have little power except near the surface, so that as erosion proceeds, a narrow shelf or marine terrace is formed just off the shore and a few feet below the level which the water reaches at low tide. The seaward edge of this terrace is built out by the accumulation of sand, and as long as the terrace is short and steep, the sand-laden waves cut away the cliffs rapidly, carrying rock particles seaward, and building the ter-

(Photo by U. S. Forest Service)

Fig. 35. These are the tops of trees which were originally about ninety feet high. From which side do the prevailing winds blow in this neighborhood?

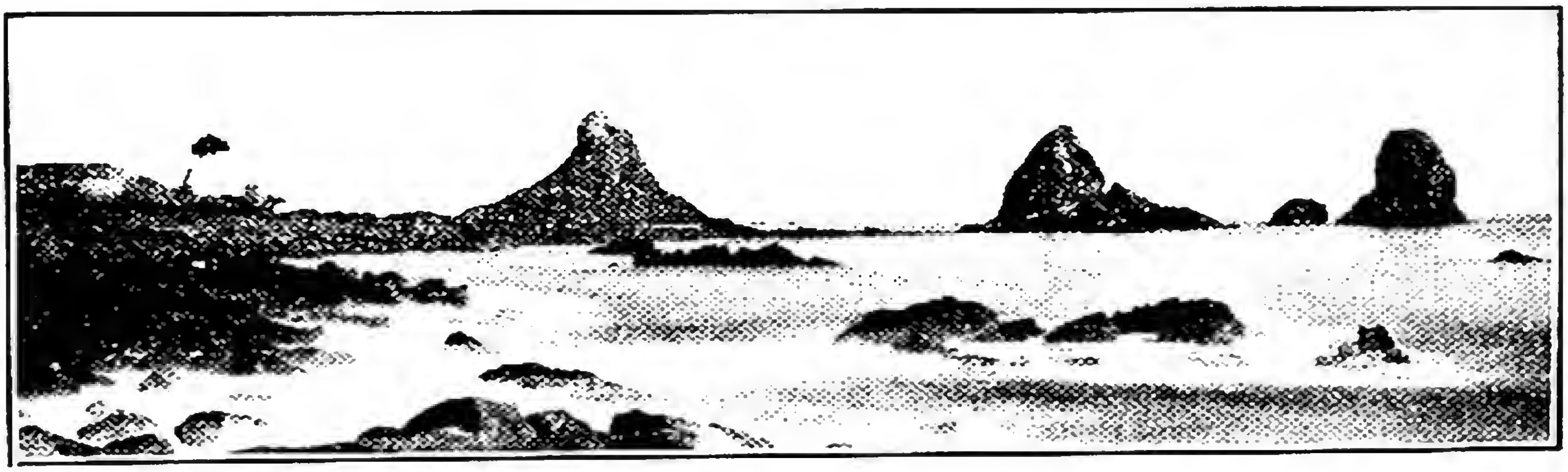
race wider. Sometimes a part of the cliff is of harder texture than the rest, and this remains for a time as an off-shore rock or island.

(Photo by U. S. Forest Service)

Fig. 36. The wind cannot blow this sand about so readily since the vegetation has grown upon it. The shrubbery came later than the sand, not earlier. How about the trees?

The shore line becomes straighter as projections are cut away and sediments fill the inlets. The marine terraces become wider and shallower, until finally the waves lose their power to erode the cliffs any further. In the inlets, which are protected from storms and strong currents, the sands may overlie the wave-cut terrace clear to the water's edge, forming beaches.

Tides are of little importance in the actual work of erosion, but since the wave-fronts are alternately raised and lowered by them, they have the effect of increasing the



(From the Gardner Collection, Harvard Geological Museum)

Fig. 37. Off-shore rocks on the Italian coast. Do you suppose these rocks are very hard? Hard in comparison to what?

width of the marine terraces. At high tide the waves dash against the cliffs and cut them away, while at low tide the sands are washed farther out to sea than they otherwise would be.

At the mouth of a river the incoming tide may be obstructed for a time, until finally it rushes up in a series of three or four great waves. Such a series of waves is called a tidal bore. Occasionally earthquakes under the ocean set up disturbances that result in immense waves. These

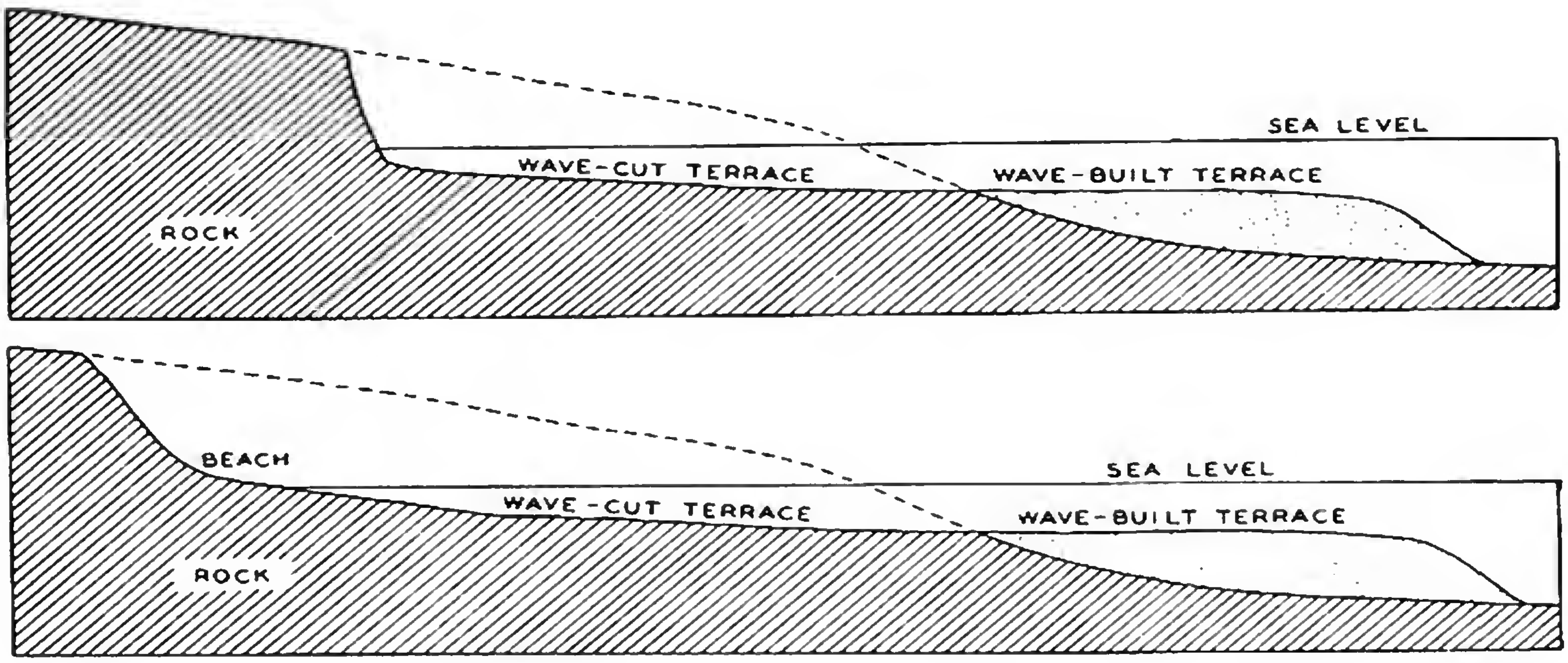


Fig. 38. The effects of wave action where the land enters the sea at a steep angle. The dotted line shows the shape of the land before the waves began to wear it away. In the lower diagram, the wave action has continued longer than in the upper, and the sea cliff has been replaced by a beach. What mistake has the artist made in the lower diagram?

are sometimes called tidal waves, but this name is an error. These earthquake waves at times attain heights as great as fifty or one hundred feet, and they have been known to destroy whole cities lying along low shores.

When a wave gets to the shore, it gets steeper and steeper until it finally breaks. The water then flows in until its force is spent, and it is drawn back to ocean level by the force of gravity. At times the backwash or undertow may be very strong. It extends out only to the line of breakers, however, and not to the depths, as has sometimes been supposed. If the line of waves does not strike straight in, a current parallel to the shore and perhaps flowing somewhat outwards at certain places may be developed. This is called

the shore current. It is not very strong as a rule. It is the combination of strong undertows with weaker outflowing shore currents at certain places, that has probably given rise to the belief that "undertows" at these places sweep with irresistible force from the shores to the bottom of the sea.

It is the combination of wave erosion, deposition of rivers, shore currents, and earth-movements that gives the ocean shore its ever-changing variety.

Questions for Review, Discussion, and Study

Chapter II

1. If you have a marble-topped table, should you be careful not to spill acid on it? Why?
2. Suppose you were to pick up a stone from the bottom of a stream, wipe it dry, and place it in the sunshine. Will its appearance be changed after it has lain in the sunshine for a time? Do you obtain any evidence that the rock is porous? Do you suppose there is water in this rock even after it appears perfectly dry?
3. How do you account for the fact that some wells can be pumped dry and then have water in them the next day?
4. If you visit a spring in the hills, and discover it to be dried up, what do you conclude?
5. Why do you suppose natural caves and caverns are not common around Boston?
6. We learned that the Earth was once very hot and that it cooled gradually. Then how is it that the ice sheet which came down over North America melted again?
7. Glaciers are made of ice. Did this freeze from water as the ice in a pond does? If not, from what did it come?
8. Are glaciers large enough to build houses on? What would be some of the consequences, as time went on, of having your house built on one?
9. How far does a very swift glacier move in a minute? Could you see it move?
10. Does a "hanging valley" really hang from something? Why do you suppose it is called a "hanging" valley?
11. Why do you suppose such a large part of an iceberg is under water?

12. Have you ever seen evidences of the force exerted by high winds? What were they?

13. How would you account for finding frosted glass in the windows of an old shack in a sandy desert?

14. Is the irregular shoreline of Maine the result of earth-movements lowering the land, or raising it?

15. Do you suppose there is anyone alive today whose grandparents can remember when there was no beach at Revere?

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CHAPTER III

WATER AND ITS WORK

Running Water

Of all the agents which wear away or erode the Earth's surface, the most important is water. We have already noticed briefly how it does this. Let us now go to the source of a stream or river and trace out the process more carefully.

Rain is falling on a high plain. The water gathers in pools, which overflow and streams form, running down hill. As the streams flow along, the smaller ones join the larger ones, making these still larger, and finally the largest ones

Fig. 39. The flat lands along the horizon are called tablelands or mesas. Is there any great difference between the way these were formed and the way the butte, shown in Fig. 40, was formed?

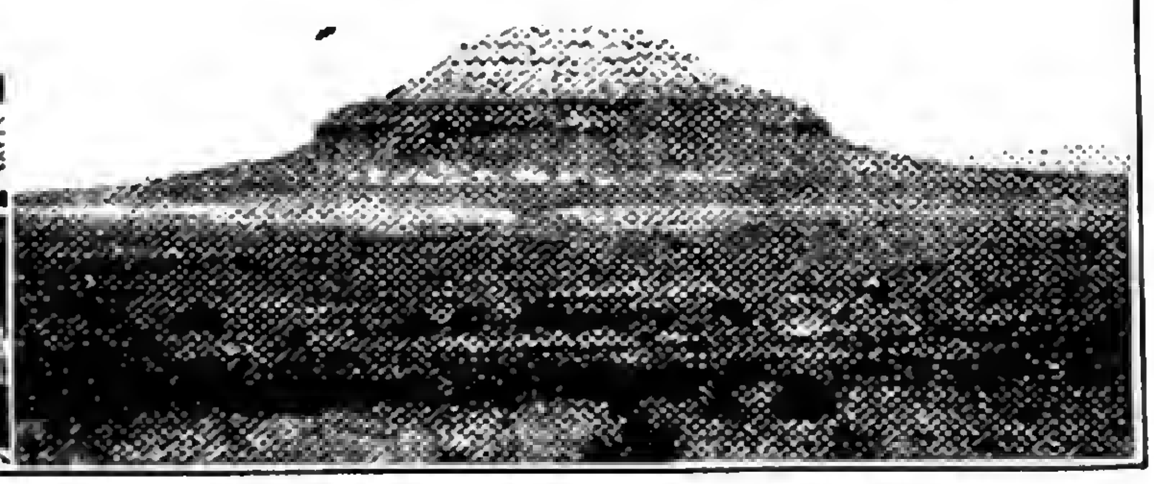
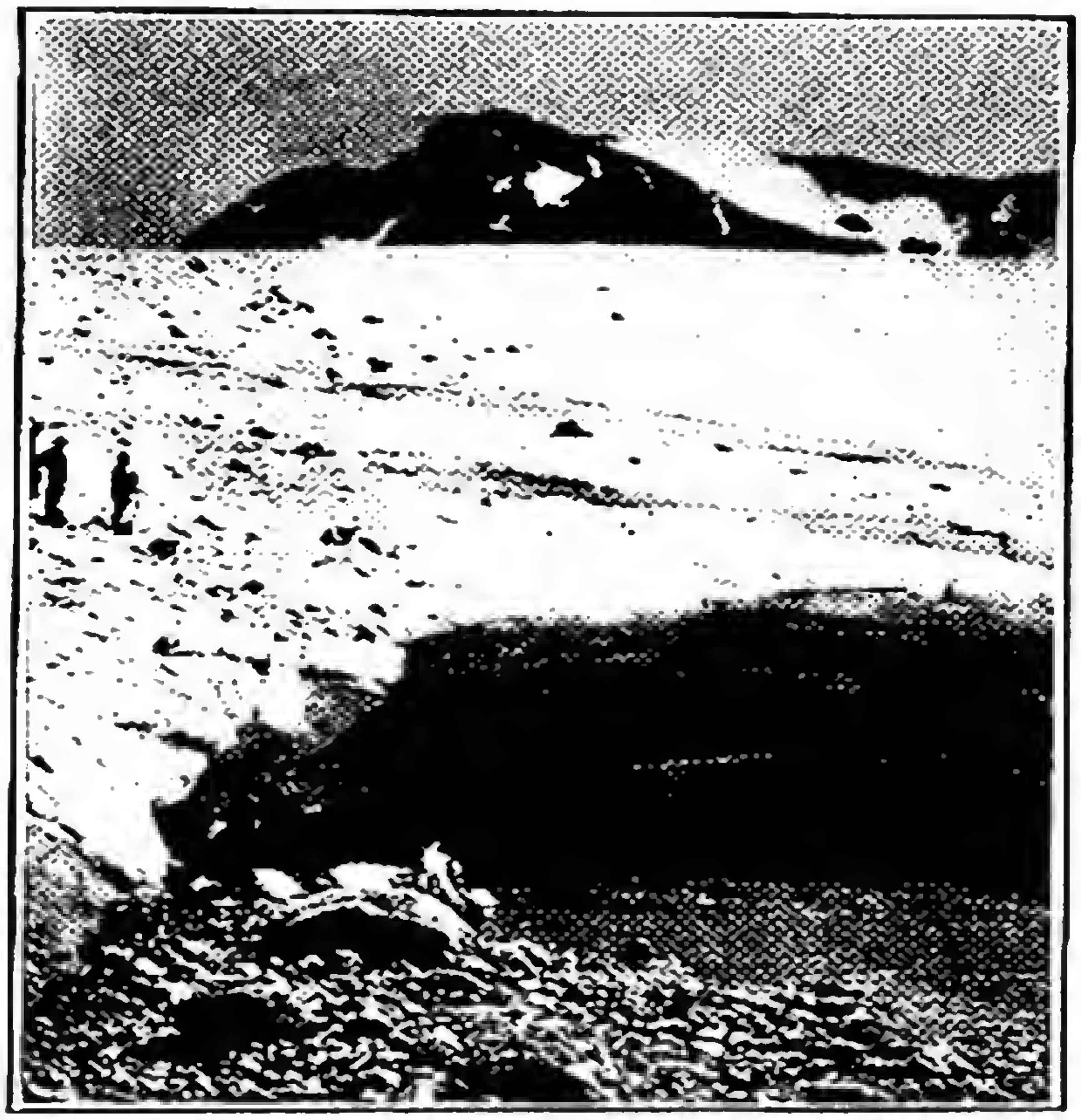


Fig. 40. This sort of "island on land" is called a butte. Can you distinguish the layers or strata making up the hill? Can you tell which are harder layers, and which are softer? Which do you think is the hardest layer?

reach the ocean. As the water flows, it moves sand, pebbles, and cobblestones, which cut away the land. Where the rock strata are soft, the cutting is more rapid than where they are hard. Sometimes a hard layer tipped at an angle is surrounded by soft layers. As these soft layers are worn

away, the hard layer is left as a hill. If the hard layer is flat, the softer ones are worn away all around it, leaving a sort of island-on-land above the surrounding country.

Running water carries materials in two ways. It carries solid particles, if they are small enough, by its speed and churning motion. When water looks muddy, it is because it is carrying a large amount of solid material. Larger particles are swept and rolled along the botom. In addition to carrying solid particles, water also carries minerals in solution, just as salt or sugar is carried, after being stirred into soup or coffee. Dissolved materials cannot be seen, yet they may be present in quite large amounts. It is estimated that if all the solid matter carried to the sea by the Mississippi River in a year were loaded on railroad gravel-cars, the train would be so long it would reach more than twice around the Earth. If all the dissolved minerals were loaded on cars in the same fashion, the train would reach about five-sixths of the way around the Earth.



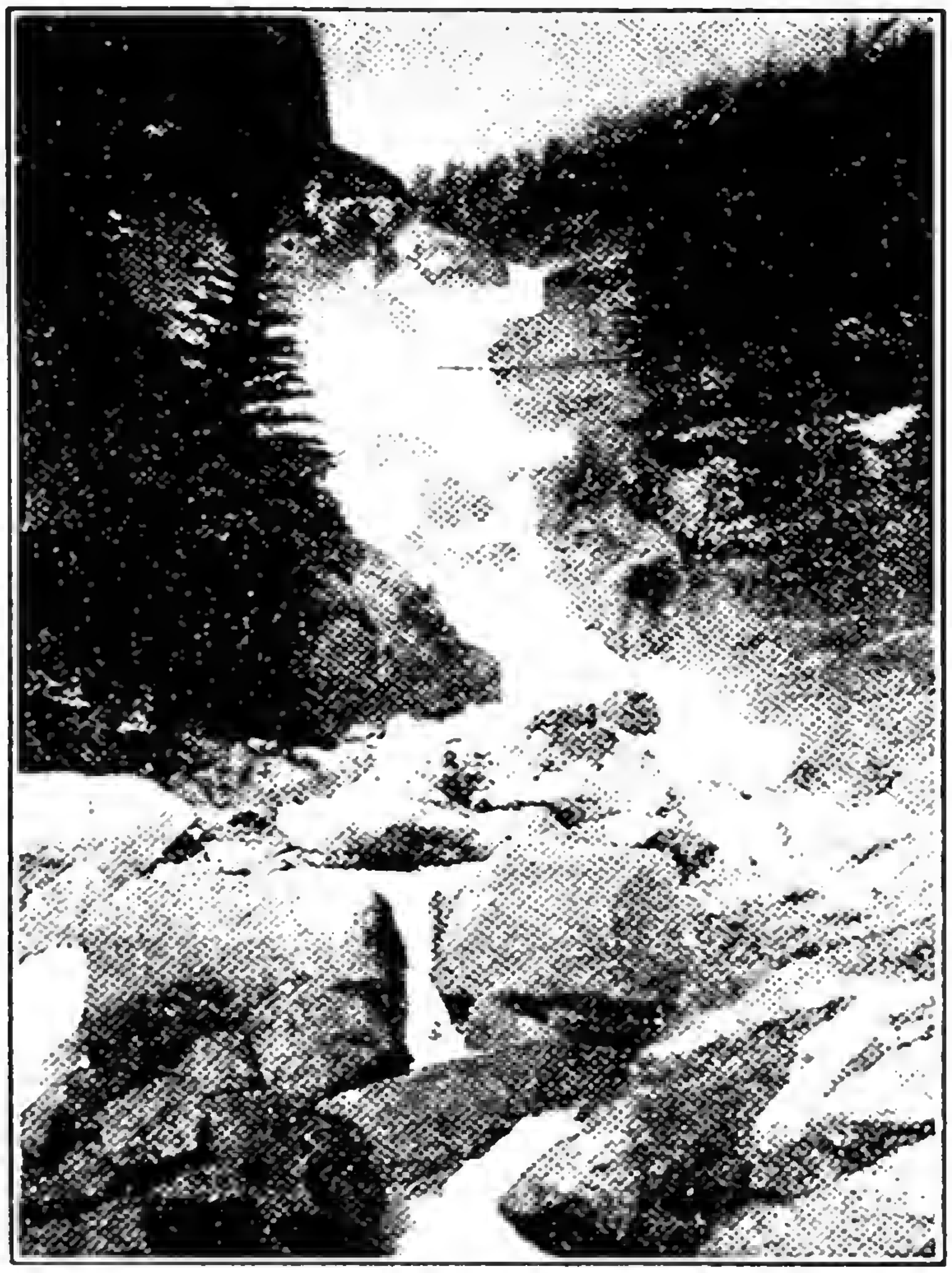
(Photo by U. S. Forest Service)

Fig. 41. A good-sized stream flows from under this icefield. It is fed entirely by the melting of the ice. At what time of the year would you expect the stream to show an increase in size and speed?

Most large streams begin in the mountains. They are fed by melting snow and rain. After a heavy storm, or in the Spring when the snow is melting rapidly, they flow with great force. Mountain streams, being much swifter than those which flow through low valleys, cut away the surface much faster. The speed of a stream depends upon the steepness of its bed, the amount of water that flows down

it, and the load of sediment which it is carrying. Its cutting power depends also upon the amount of sand which it carries. Absolutely clear water has very little cutting power as compared with muddy water or water carrying larger particles of sand.

The size of particles that a stream is able to carry depends on its speed. If the speed is doubled, the stream can carry sixty-four times as much material as before. A small stream may be swollen by a heavy shower, which for a time increases greatly the amount of water flowing in it. This increase in amount of water causes an increase in the speed of the current, and this in turn brings about an enormous increase in the size and number of particles carried. This is the reason why floods and torrents are nearly always muddy. The added "tools of erosion" combined with the added volume and speed of the water, give an immensely greater cutting power to such a stream. It is at flood times that much of the real work of erosion occurs.



(Photo by U. S. Forest Service)

Fig. 42. Note the size of the rocks in the bed of this mountain torrent. Why is there no sand or gravel visible?

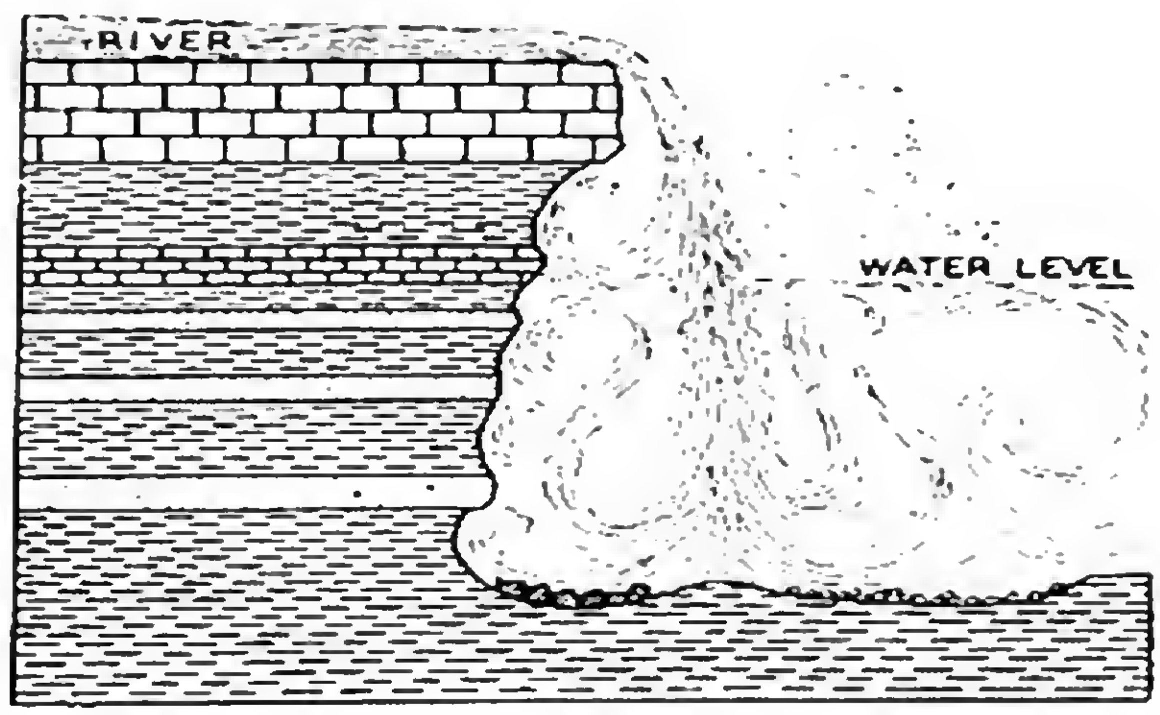
Stream Erosion

Where a stream flows over solid rock, the sand particles scrape and scour the bottom and sides of the stream. Eddies in the water cut curious hollows in the stream bed. At flood time large stones are rolled and swept along the

bottom. Their corners are chipped and scraped off, and they come to have a rounded appearance. When the flood goes down, these stones are left resting along the bottom and sides of the stream. Since the stream as a rule flows faster in the middle than at the edges, most of them are deposited at the sides.

Fig. 43. How do the shape and position of the boulders tell you that a stream once flowed over this rock? What evidence is there in the picture to show that the stream action took place a rather long time ago?

A waterfall occurs where a stream flows from hard rock to softer rock. The softer rock is eroded faster, and the waterfall results. At some places a layer of hard rock rests on top of softer layers. At the lower end, the river may cut away the softer underlying rock as it falls, the eddies cutting back under the harder layer, which chips off from time to time. Often a large block comes down, as happened at Niagara in 1931. The waterfall thus retreats gradually up the stream until it comes to the end of the hard layer and disappears.

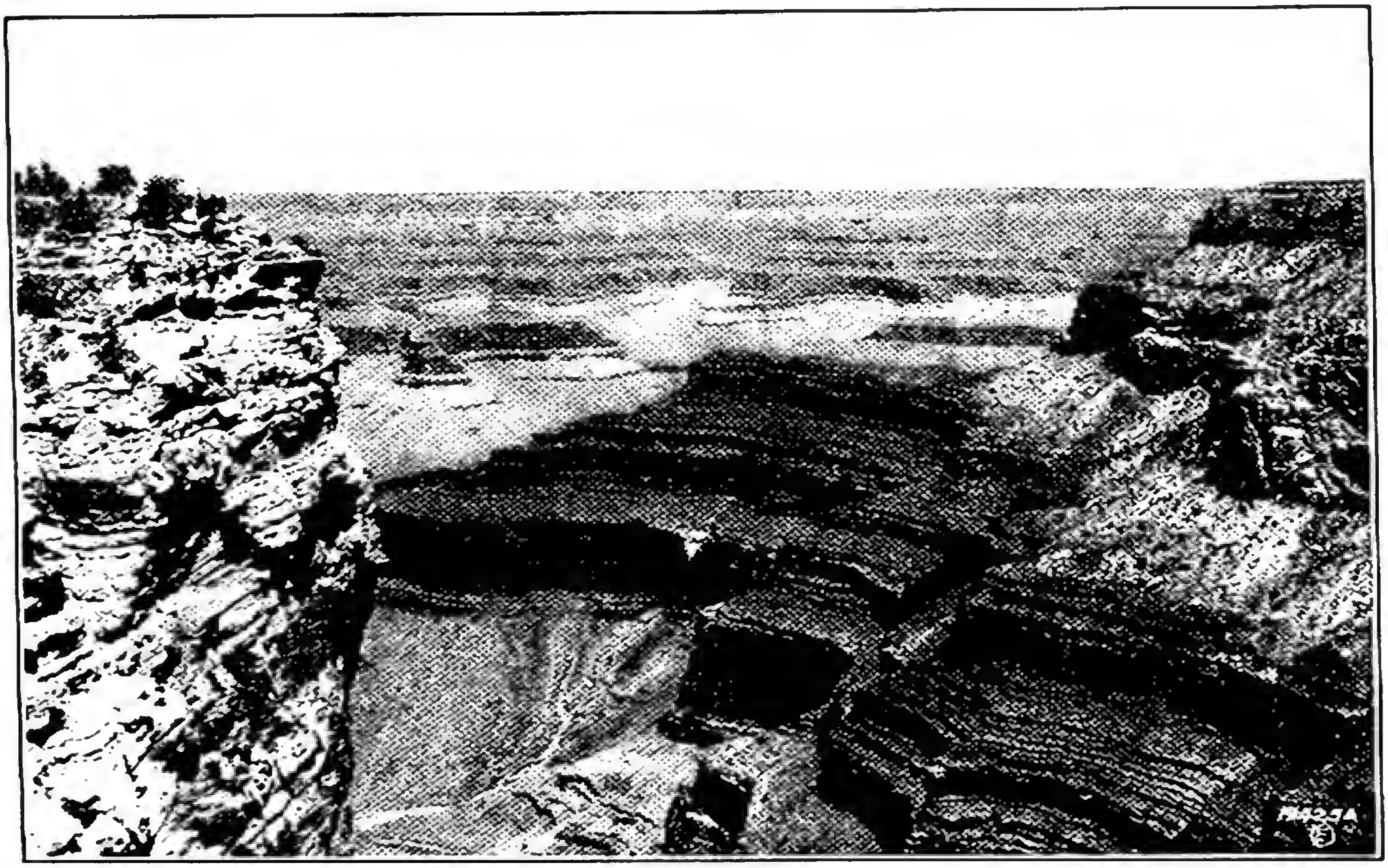


(After Gilbert)

Fig. 44. This diagram of Niagara Falls shows the hard uppermost layer and the undercut softer layers. Can you pick out other hard layers? Where did the rocks which are lying under the falls come from?

Canyons are formed when a section of land rises with some rapidity (more than a foot or two a century) by Earth-movement. When such a movement occurs, the streams gain greatly in speed due to the increased steepness of their beds. They are then likely to cut straight down, forming deep

canyons and gorges. The Grand Canyon of the Colorado, in Arizona, was formed in this fashion. If the rock is soft the stream may never cut a gorge. The sides of the cut will cave in and be carried away and a V-shaped valley will result.



(Photo by U. S. Forest Service)

Fig. 45. A view of the Grand Canyon. Notice the very flat skyline What does it indicate about the form the country would have if the canyon had not been cut into it?

In the course of time all valleys become broader at the top. They widen until their outer rims meet the outer rims of other valleys. The ridge formed by the meeting of two valleys is called a divide. Where a smaller stream or tributary enters a larger stream the divide between these two streams vanishes. As a river system grows and cuts away the land, it develops a drainage basin. The principal divides are called Continental Divides. They are the ridges or

highlands between the basins of great river systems. At some places a Continental Divide may be a broad highland. In other places, or after the passage of many centuries, it may be a narrow ridge.

Lakes

Lakes are made in many ways. Wherever there is a basin in the Earth's crust, there is likely to be a lake, unless the country is so dry that evaporation takes place faster than the rain can fill up the hollow.

One of the causes of formation of a lake is the damming of a stream. This may come about through a landslide or a lava flow at a comparatively narrow point in some valley.

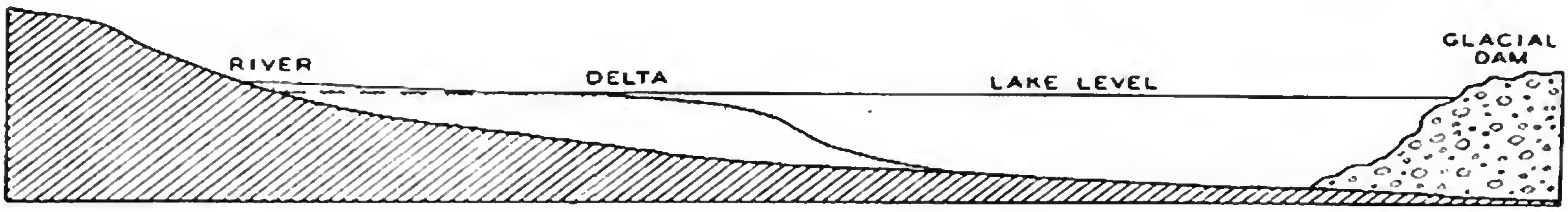
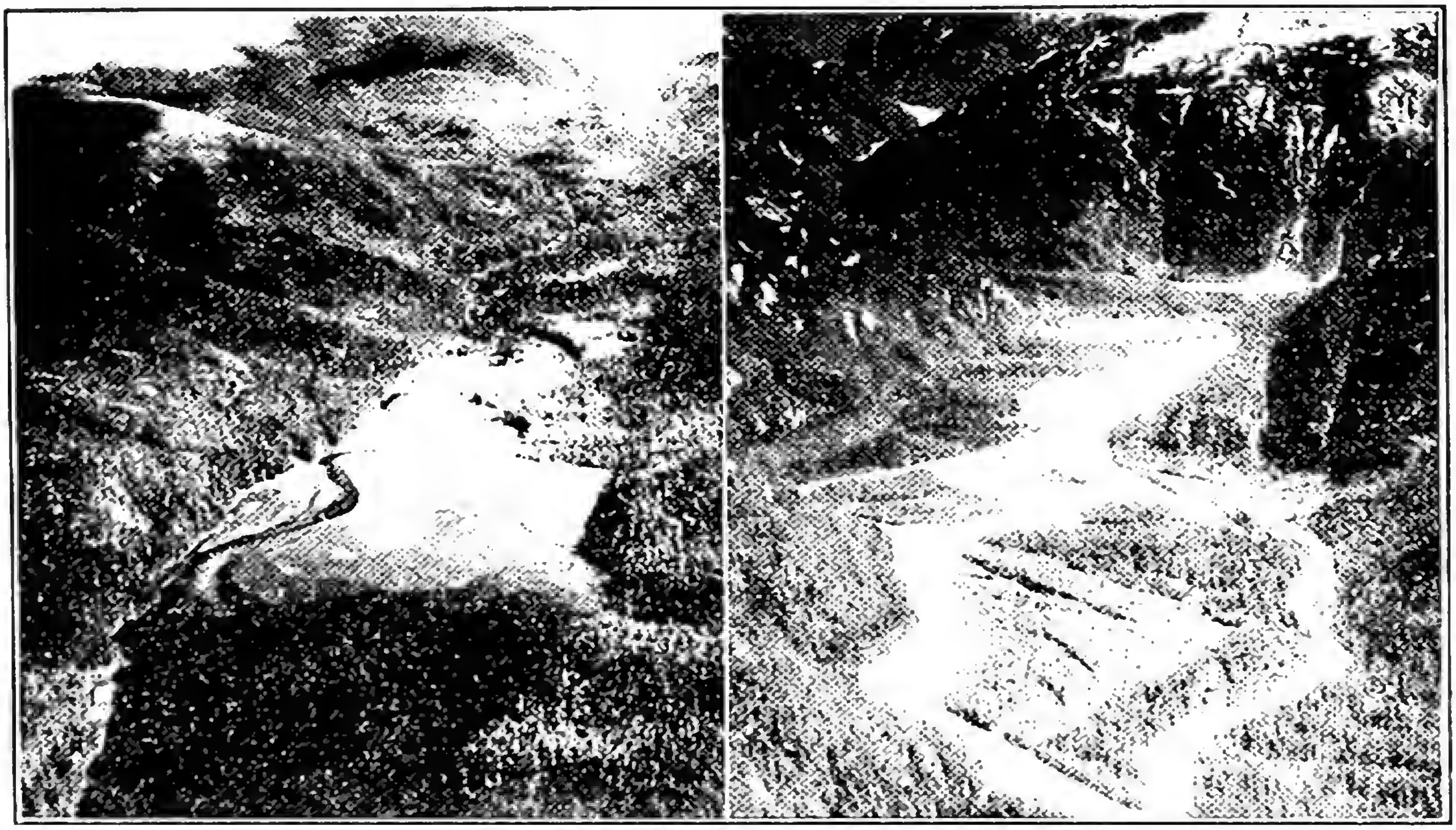


Fig. 46. This diagram illustrates how a lake may be formed by a river flowing in an old glacial valley. Note the delta in this lake. Compare with Fig 30. Is there a delta in Fig. 30? Explain.

The water will then fill the basin until it overflows the top of the obstruction. If the stream is heavily loaded with sediment, this will be deposited in the lake. The speed of the water is much slower across the lake than where the stream is narrow, and we have seen that the carrying power, for solid particles, depends on the speed of movement of the water. Thus the lake basin is gradually filled up with sediment, from the inlet toward the outlet. At the point where the overflow occurs, erosion commences. If the dam is composed of hard materials, the clear waters will be very slow in the work of cuting a new channel through the dam, until the filling has proceeded so far that noticeable amounts of sediment still remain in the main current by the time it gets to the point of overflow. But in any case, no matter how slow the action, the result in the end is the same. The

bottom fills up with sediment and under-water or edge-water vegetation, and the outlet is cut away until the water all drains off and there is no more lake. Many of the most fertile valleys are the beds of ancient lakes.



(Photos by U. S. Forest Service)

Figs. 47 and 48. These airplane views show two stages in the process by which a river fills up a mountain lake. On the left the river has carried much material out into the lake and is now meandering through the resulting delta. On the right is a similar view of another valley, in which the lake has been completely filled and vegetation is growing on the filled-in land.

Lakes may be formed in many other ways. Sometimes a whole section of land may sink. If the lower end of a river basin or valley is lifted by earth-movements while the upper end is not, we have another process by which lakes are often formed.

A glacier may scrape out a valley, and then as the climate of the region becomes warmer, deposit heaps of rock material and rubbish at the lower end until a basin is formed and a lake develops. This may take place on a very large

scale. The Great Lakes were formed in this way, and they cover thousands of square miles of the Earth's surface.

Experiment 7. Find or build an open box about 6 inches wide, 4 inches high, and 18 inches long. One end of this box should be removed. In the first 6 inches of the other end, pack in tightly a

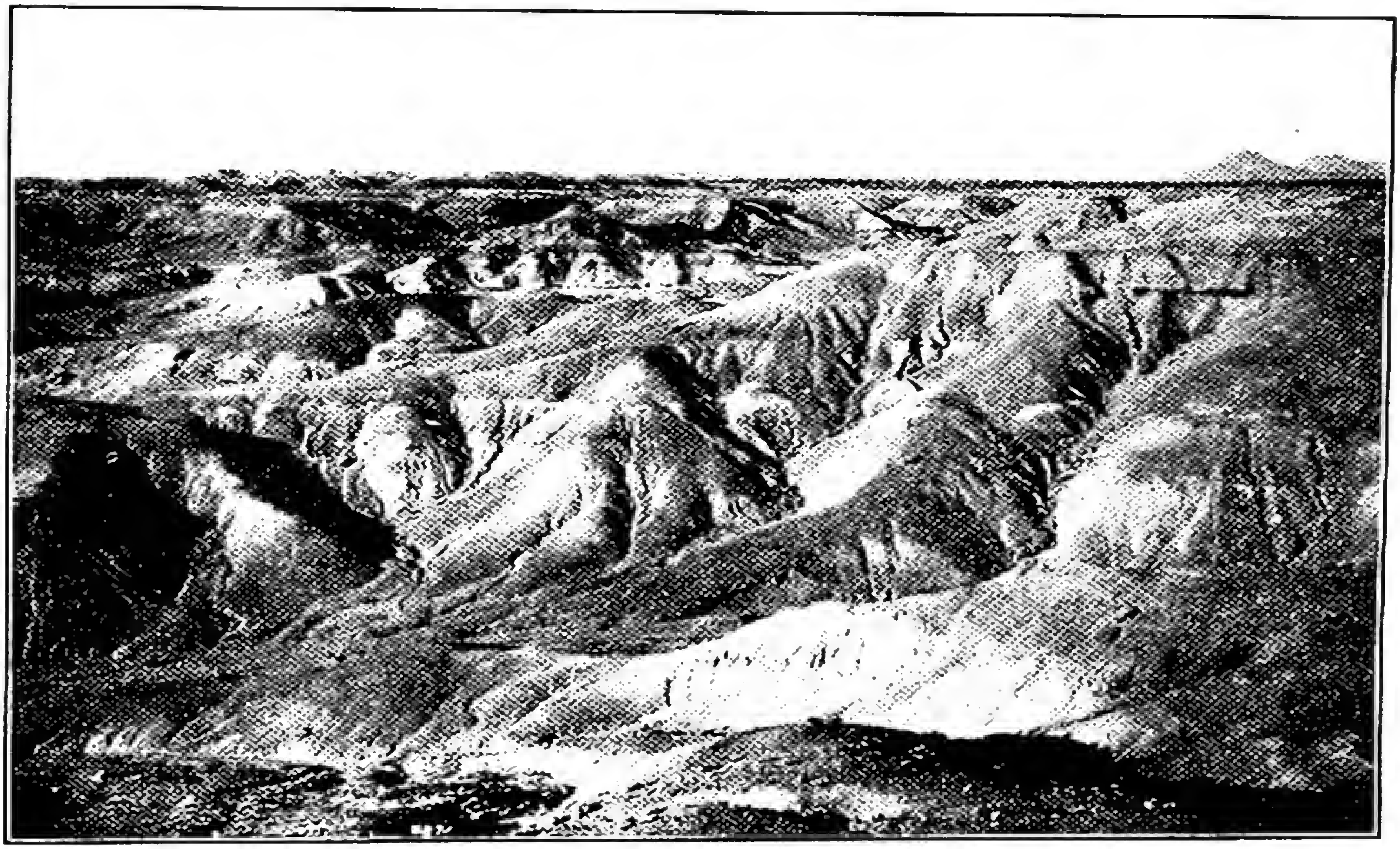
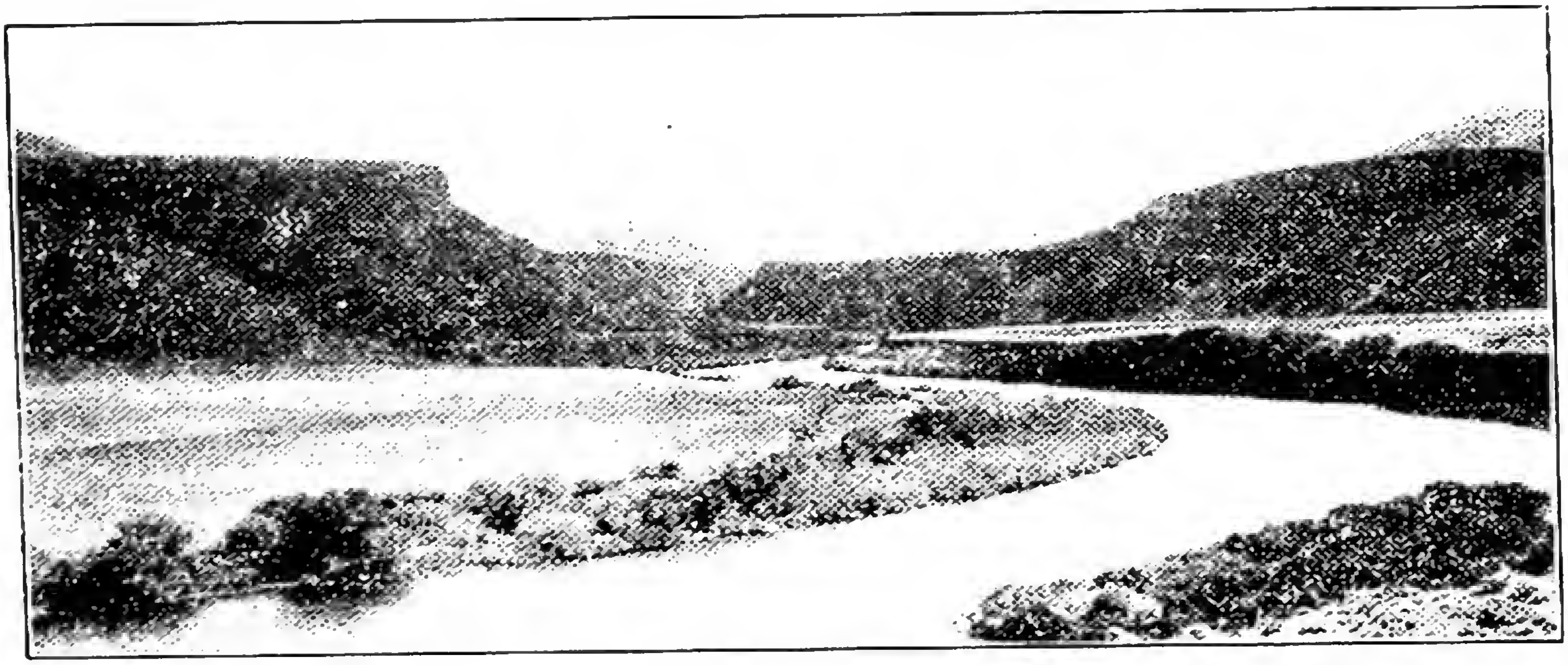


Fig. 49. The effects of running water. Note the V-shaped valleys and sharp ridges in comparison to the rounded appearance of the glaciated country shown in Fig. 28. Note here also the flat skyline. What does it tell concerning the origin of this region?

layer of fine clay soil to a height of about 3 inches. Fill the next 6 inches with loose sandy soil to the same depth, packing fairly well but not so tightly as in the case of the clay. Set the box with its open end over a sink. Arrange a hose with a small sprinkler to sprinkle the first 3 inches or so of the clay next to the closed end of the box. Turn on the water to give a fine drizzle and observe what happens. Let the drizzle continue for several hours and note the results.

Rivers and River Valleys

High regions with many lakes and streams running in canyons and narrow valleys are eroded into low, broad valleys and plains, if earth-movements do not raise them again before the process is finished. The Mississippi River basin is a good example of such a region.



(Photo by U. S. Forest Service)

Fig. 50. River terraces and meandering stream. Is there more than one level of terrace? Are the hills in the extreme background formed by terracing? How can you tell.

Sometimes a wide valley or plain is lifted by earth-movements. The river then cuts down again until it reaches base-level—the grade or angle of descent at which deposition just balances erosion—and no further downward cutting occurs. When base-level is reached, the river begins to cut under its banks on the sides. Cave-ins occur, and the valley is gradually widened. As it goes around a curve, the water flows faster on the outside of the curve than on the inside. Hence erosion occurs on the outside and deposition on the inside. The river comes thus to have a very winding course. The loops and twists are called meanders, and a stream that has meanders is called a

meandering stream. Such a stream tends to widen its valley and reduce the general level to within a few feet of its own base-level. If another earth-movement occurs that lifts the land still higher, the river begins to cut down again instead of sidewise, and we find a step-like terrace on its bank. Sometimes successive uplifts result in a stream having half a dozen or more terraces.

Meandering streams sometimes enlarge their loops until these look like horseshoes. The neck of such a loop becomes narrower and narrower, until finally at some flood-time it is cut through entirely, and the stream takes a new and shorter course.

Deltas

Wherever a stream flows into the ocean or a lake or a larger, more slowly moving stream, sediments are deposited. These deposits are called deltas, after the Greek letter of that name (Δ). They are fan-shaped as a rule, being narrow at the upper end and widening gradually as the stream is lost in the larger body of water. Some deltas are only a few feet long, while others, such as the delta of the

(Courtesy U. S. Bureau of Chemistry and Soils)

Fig. 51. Soil deposited by a river. This picture shows the soil to a depth of about eight feet. (See Fig. 31.) How can you tell it is sedimentary in origin? How can you tell it is not glacial soil?

Mississippi or that of the Nile, extend for miles and miles. The outer edge of a delta is always under the water, while its upper parts are usually on the land.

Sometimes a small stream or a seasonal torrent descends into a dry valley or plain and is absorbed into the ground or evaporates. In this case a deposit similar to a delta is formed at the mouth of the valley or canyon.

Floods and Flood-Plains

Soil is washed from the mountains by streams. As these streams reach the lower valleys they lose their former speed, and deposit the soil they have been carrying. In flood times the Mississippi, for example, overflows its banks in the lower stretches and deposits its sediment over great areas. The floods themselves are often destructive, but the material deposited is very fertile. The area over which deposition takes place is called the flood-plain. The first great civilizations of the human race grew up on the fertile flood-plains of the Tigris, Euphrates, and Nile Rivers. The soil deposited by streams is usually fine and dark.

The Soil

Soils are classified according to their origin and the size of the particles of which they are composed. If the particles are large, we have a sandy soil. If they are all very small, we have a clay. If they are of a medium size or mixed, the soil is called a loam. Loams are usually considered better for cultivation than either sands or clays. Soil that originates from the decomposition of organic matter is called humus. Humus is also necessary in a good crop soil.

In a sandy soil, water flows quite freely and is absorbed only slightly. It sinks right through such a soil, and the soil soon dries out again. Sandy soils get very warm in the bright sunlight, and cool off rapidly at night. Water is absorbed by clays to a considerable degree. The clay becomes sticky when it is full of water, and prevents any

appreciable flow. In the sunshine, clay is baked to a hard surface. It cracks and permits the water in lower layers to evaporate. Later rains find much difficulty in soaking into the hard, rock-like blocks. Humus absorbs water too, but it does not become sticky, so the water is able to flow through it. A pure humus soil is likely to be acid, however, and it is very light. It is therefore just as unsuitable for crops as a pure sand or a pure clay.

Humus is formed by the decay of vegetables and animal matter. This is best brought about by the action of bacteria a few inches under the surface, where the sunlight does not penetrate. The process takes place most rapidly in places where there is a thick mat of leaves and grass. The lower layers of the mat decay and combine with the soil, leaving the more resistant twigs and leaf skeletons intact for a time. Farmers often plant crops and then when they come up, plow them under again in order to add humus to the soil. The woody fibers of twigs and logs are attacked more slowly by molds and other fungus plants. But after continued attack, even wood becomes crumbly and rotten, and finally falls to pieces and becomes a part of the soil.

If it were not for the action of animals, most of the humus would be at the top of the soil, rather than mixed with the rock-particles. The most important animal engaged in the mixing of soil is the earthworm. Earthworms burrow through the upper layers of the soil in all directions. They bring rock particles to the top and humus particles to the lower layers. Since they eat nothing but soil, which has a low nutritive value, they must eat and excrete great quantities of this in a day. The earthworm practically eats his way through the ground. Without earthworms, the soil would be far less fertile than it is. Gophers, moles, ants, and a few other animals also burrow in the ground and help to loosen and mix the soil. Man with his farming implements does the same thing on a much larger scale.

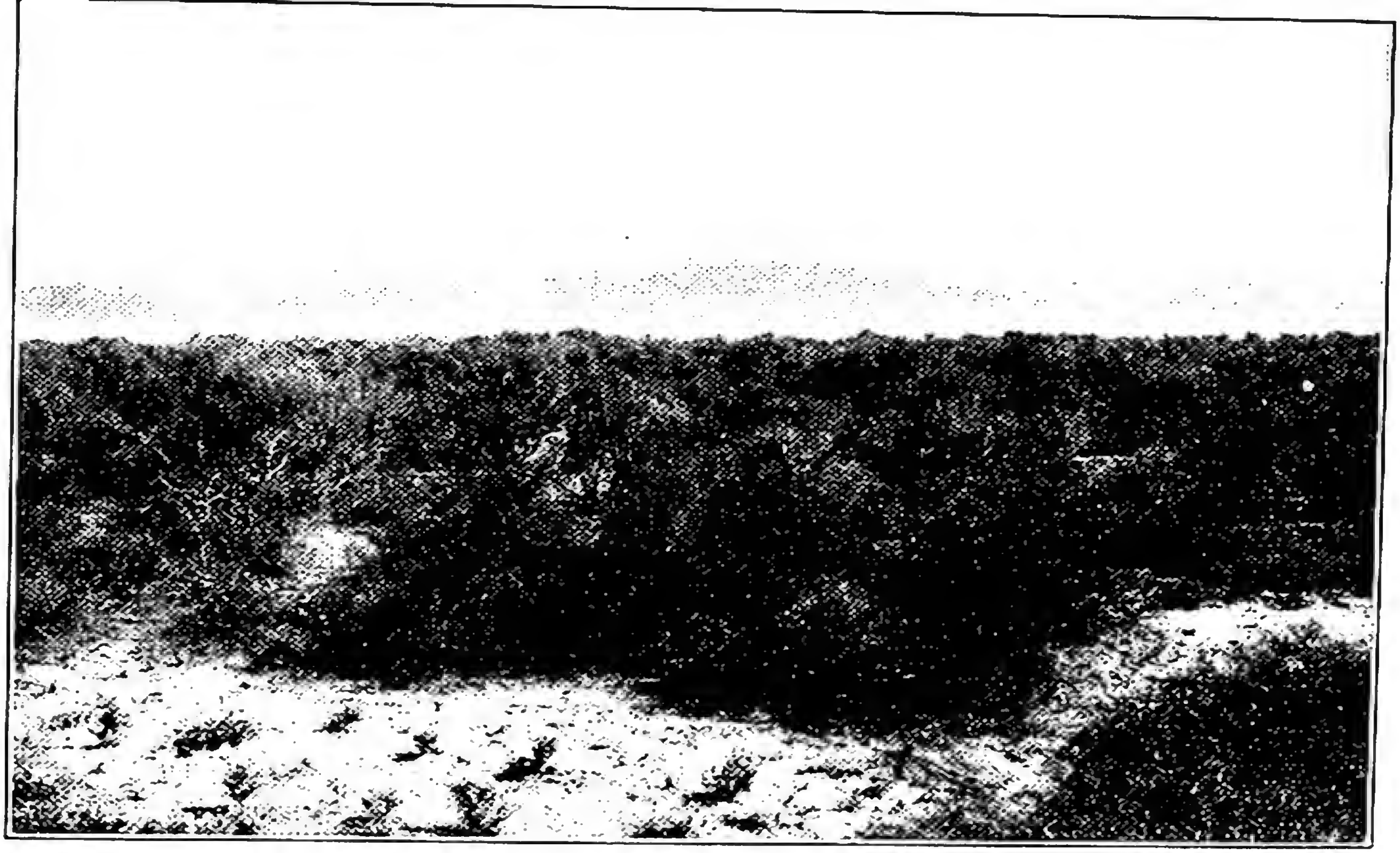
A good soil should contain some sand, some clay, a certain amount of humus and water. If there is enough water and humus, the clay may be absent. If the clay is sufficiently broken up and pulverized, the sand may be absent. Humus and water must always be present. Most waste lands, such as deserts, owe their condition to the fact that there is insufficient water available. As soon as these lands are irrigated and fertilized with a little humus, they become excellent farm lands. Many new and fertile areas have been opened by modern methods of irrigation.

The soil contains several minerals that are necessary for plant growth. Some plants use up one mineral and some another. Many plants when they die deposit one or another of these minerals in the soil again when they decay and are changed to humus. In the forest and jungle many plants of all kinds grow side by side, and the ground stays fertile. In farming, however, the same crop is often grown year after year until some important mineral is gone from the soil. The farmer must then resort to artificial fertilizers, or he must grow some other crop that replaces by natural processes the mineral removed. The development of the science of crop rotation and artificial fertilization of the soil is one of the great advances of civilization in recent years.

Experiment 8. Collect specimens of soil. Heat one of them in an iron pan. If it chars or blackens, and smokes, it contains humus. Grind up what now remains and drop a heaping tablespoonful into a quart jar or milk bottle 3/4 full of water. The sand, if there is any, will settle to the bottom at once. Clay particles may require several hours to settle, during which time the water will appear cloudy. The next day, pour off some of the water from the top of the jar, being careful not to disturb the deposits on the bottom. Boil this in a clean enamelled pan until all the water is gone. If a deposit is formed on the sides or bottom of the pan, it shows that the water contained dissolved minerals.

Deforestation and Water Conservation

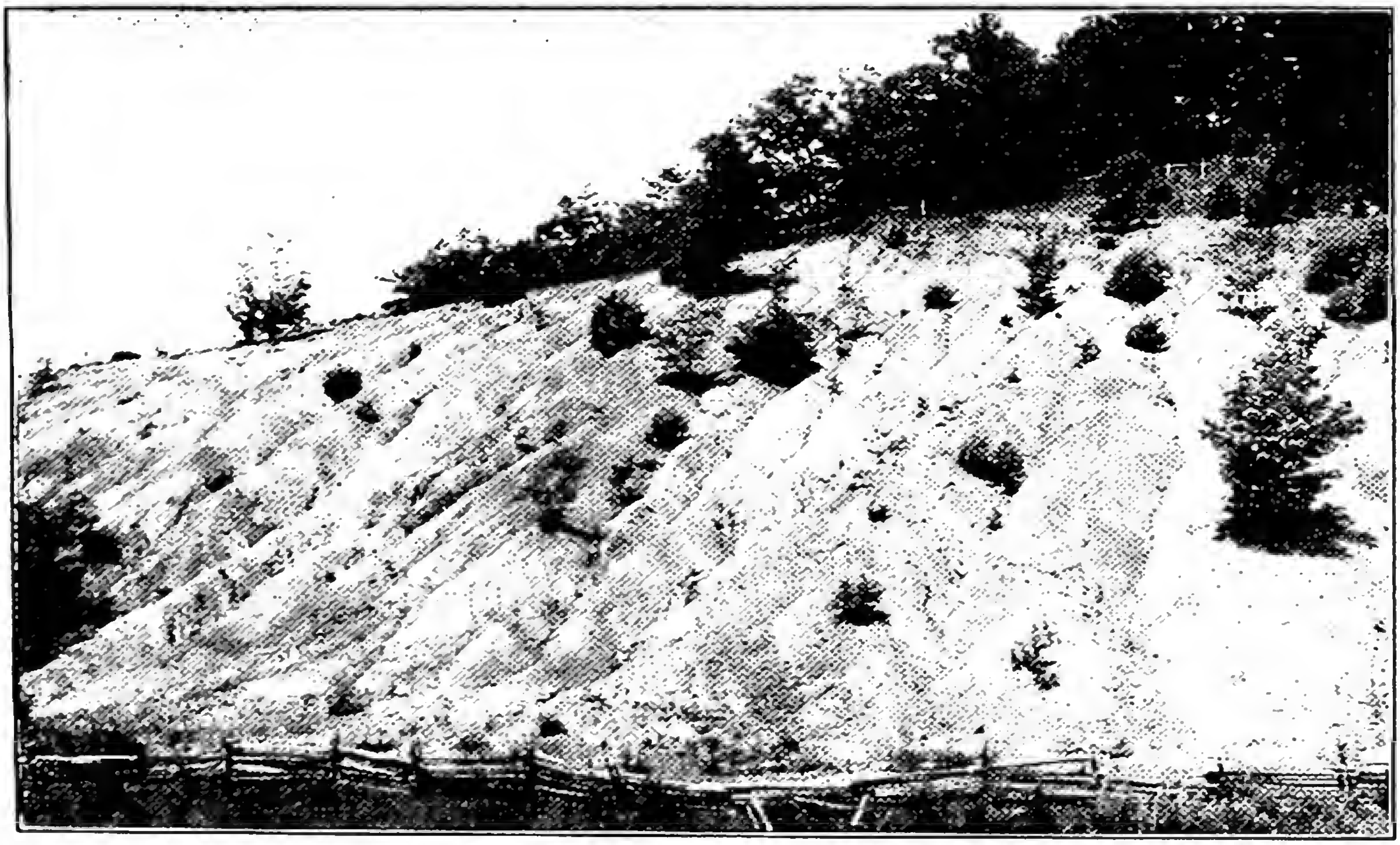
Water falling in a forest does not strike the earth with any great force. The leaves and branches of trees and



(Courtesy U. S. Bureau of Reclamation)

Figs. 52 and 53. Two pictures of the same valley in Idaho. The upper picture was taken just before irrigation was begun, and shows the arid waste land as nature left it. The lower picture was taken a few years after the valley was put under irrigation, and shows a crop of sugar beets growing. Idaho is now well-known for its sugar beets.

underbrush break the force of the rain. Their roots also bind the soil together, and the mat of dried and drying leaves and grass lying on the ground absorbs much water and lets it seep slowly away. As a result, erosion in forested regions proceeds slowly, and the water table remains relatively close to the surface.



(Photo by U. S. Forest Service)

Fig. 54. The trees which formerly covered this hillside were cut down a few years ago. Were the gullies made before, or after, the deforestation? Do you think grass grew on the hill before the trees were cut down? Would it do any good to plant grass on this hill now?

If these forests are now cut down, the mat of leaves and grasses turns to soil in a few months or years, and there is no new mat above it. The rain strikes down on the bare soil and washes it away instead of sinking down into it as was the case when the forest was standing. As a result, erosion proceeds rapidly, and the water table goes down. If a layer of porous rock comes to the surface on the side

or top of such a hill, artesian wells miles away may dry up as a result of the cutting down of the forest. In many regions where artesian wells form the main source of the water supply of some valley, it is necessary to avoid the cutting down of forests in near-by hills.

In some cases where the hills have been deforested and

(Courtesy U. S. Bureau Chemistry and Soils)

Fig. 55. This sloping countryside in Oklahoma was abandoned thirty years ago because water flowing down the slope had washed away the soil. For the last two years a good crop has been produced on it. What has the farmer done to prevent his land from being washed away?

put under cultivation, the soil in a few years has been washed away, and neighboring valleys have had to face serious water shortages. The science of forest and water conservation has reached such a stage by now, however, that the remedy can usually be found. The necessary regions can be reforested and the water supply restored. Farmers have learned that by placing ridges across the line

of flow of the water that drains down the hillsides, the cutting of gullies and eventual erosion of the land can be checked, and the water caused to sink into the ground as it did when the land was covered by forests.

Experiment 9. Field Trip. Visit the ocean shore where a stream flows in from the mountains. Observe the rocks. Try to find igneous, sedimentary, and metamorphic rocks. Examine the valley or canyon cut by the stream. Look for terraces, meanders, and gorges. There may also be a lake or pond. Look for deltas where the stream enters a lake or the ocean. Observe the action of the ocean waves on beaches and cliffs. Try to imagine what the region must have looked like a million years ago, and what it will look like a million years in the future.

The Surface Features of the Earth

If there were no earth-movements, all the land would eventually be washed into the ocean. But uplifting movements are continually taking place. In the United States at the present time, the central and eastern portions are being eroded, but the Pacific Coast is rising fast enough so that the net gain of uplift over erosion amounts to about an inch a century. The land surface of the United States as a whole is being lowered by about one inch in 760 years.

Streams running from a range of mountains to the sea cut away the seaward faces of the mountains and deposit the materials at the water's edge. After the passage of many centuries, during which the valleys widen and merge and the deltas grow and join, the whole area comes to assume the appearance of a wide plain. Later earth-movements may raise such a plain to a higher level, when erosion will again set in. Much of southern New England consists of old uplifted plains of this sort. Erosion has already done considerable work here. The fact that the land is an ancient plain may be observed by noting the almost flat skyline where high regions lie along the horizon.

The surface of the Earth is forever changing, but always slowly. At one time erosion may be faster than uplift, and

at another uplift may be faster than erosion. But on the whole the two tendencies nearly balance. There are always oceans and there are always continents. There are always mountains and there are always valleys. The face of the Earth changes its expression, but it does not become expressionless.

Fig 56. A first glance at this picture might lead to the idea that it was taken in the mountains. But notice the skyline. Isn't the land quite flat except where the river has cut into it? The region is really an ancient plain.

Questions for Review, Discussion, and Study

Chapter III

1. How could you tell the difference between a hill that had once been underneath a glacier and one that had never been acted upon by glacial ice?
2. Most of the rocks and pebbles in the bed of a stream are rounded and smooth. How do you account for it?
3. How do you explain the fact that mountain streams are so clear and lowland streams sometimes so muddy?
4. Can you think of a possible disadvantage in having the boundary of your land determined by a stream?
5. Why do you suppose a stream flows faster in the middle than it does at the edges?

6. Do you suppose Niagara Falls will always be where they now are?

7. The text says, "Where a tributary enters a larger stream, the divide between these two streams vanishes." Does that mean that it just disappears, while you are standing looking at it? What does it mean?

8. Do you know of any lakes which have no outlets? What sort of lakes are they? Why?

9. Were the lakes in New England formed by earth-movements? If not, how were they formed?

10. Why does water in a river flow faster on the outside of a curve than on the inside?

11. Look up the word "meander" in a dictionary. Do you ever meander? Do you think "meandering" is a good word for a winding stream?

12. Do you suppose many deltas are shaped just like the Greek letter "delta?" Which side of the letter "delta" does the "outer edge" of a river delta represent?

13. If you had sandy soil, clay soil, and a mixing machine, could you make a loam?

14. If every year you saved all the dead leaves in your street, couldn't you have a huge bonfire with them ten years from now?

15. What is meant by "crop rotation?"

16. Do you know of any artesian wells? Where are they?

17. Suppose your water came from an artesian well, and the well dried up. What could you do about it during the ensuing week?

CHAPTER IV

PLANTS AND THEIR FUNCTIONS

Life on the Earth

We have seen in the last few chapters that many vast changes took place on the Earth before it was in a condition to support living things. Many changes in the Earth's surface would go on and on, even if there were no living things upon it. Indeed the changes in the Earth produced by the life upon it are relatively unimportant when compared with the changes brought about by non-living agencies like rain, wind, and glaciers. But to man, living things are of vital importance. Without them he himself could not live. They are therefore just as significant to us as are the other features of the Earth on which we find ourselves.

Living and Non-Living Things

Nearly everyone can tell living things from those which are not alive, yet no one knows just what life is. Perhaps the best way to tell the difference is to note the things which living things or organisms *do,* that non-living things do not. There are three main sets of functions that separate living things from those which are not alive. We shall examine each of these briefly.

What Living Things Do

Living organisms—plants and animals—tend to keep their basic structures the same amid all sorts of changes in the environment or surroundings. For example, an oak tree tends, as long as it lives, to remain an oak tree, and to live as oak trees do, no matter what may happen to it. To maintain their basic structures amid varying surroundings, plants and animals perform several acts. They

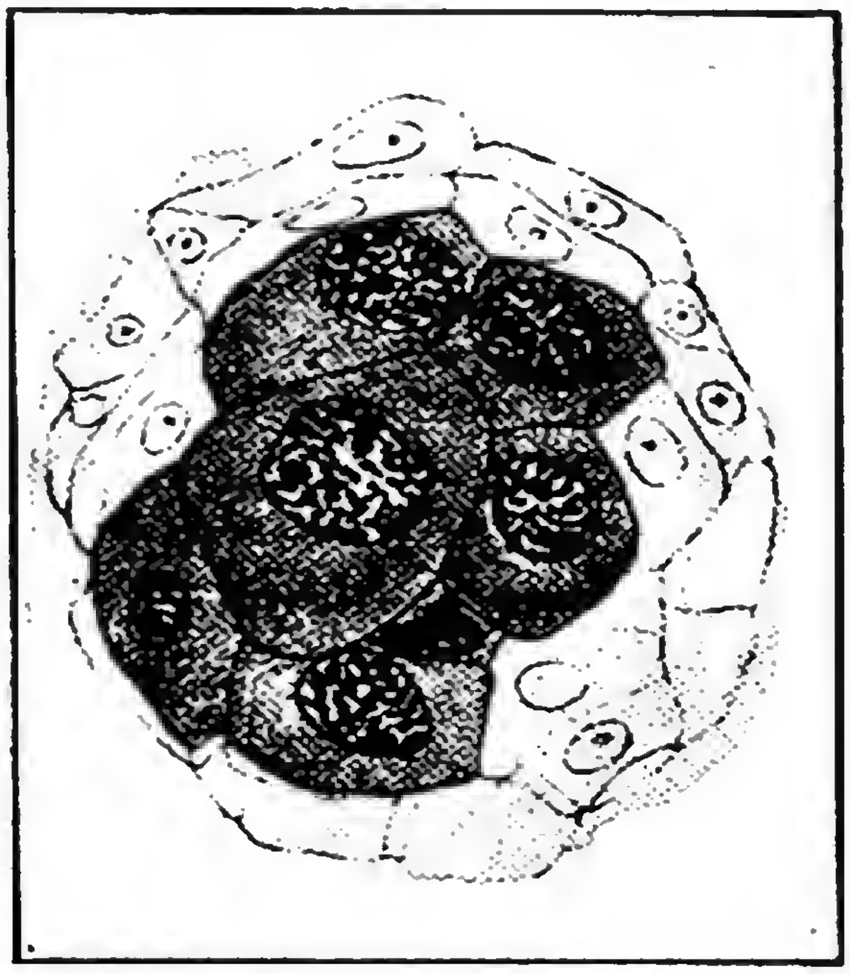
take in food, they breathe oxygen from the air, and combine it with the food to set free energy. So far, they are no different from any engine, which burns fuel and oxygen and does work. But there is one important difference; an engine does not repair itself, and an organism does. A part of the food taken in by a living thing is used to build up and repair its body. Furthermore, if it is broken or injured, it sets out at once to repair the damage. As a rule it succeeds, unless the injury is too great. If the food taken in is not in the proper form to be used as fuel, the digestive system, acting as a sort of chemical works, changes it into the right form. Of course, certain kinds of materials, as for example sand, cannot be changed into food at all. Useless materials are removed or excreted from the body. This general process by which living things produce energy and maintain their basic structures, is called metabolism.

Living organisms grow and reproduce their kind. They go through a regular cycle of changes, from infancy to youth, maturity, and old age. Finally they die. But during the period of maturity they reproduce others. These others grow to maturity in turn, and repeat the process. Living things, then, tend to perpetuate their general types or species on the Earth, even though the individuals must perish.

Living organisms adapt themselves to their surroundings. They respond or react to changes in the environment. Plants do this mainly by changing their rates of growth in different parts, and by modifying the details of their structures. Animals respond to changes in their environment mainly by bodily movements. But some plants, such as the sensitive plant, are able to move in response to stimulation, and some animals, such as the chameleon, modify their external structures in response to various situations. These movements and modifications of detailed structure help to preserve the individual and through him, the species. This tendency of living things to respond to stimulation is called irritability.

PROTOPLASM AND THE CELL

In addition to the three basic functions which we have just considered, living organisms have another general feature which distinguishes them from non-living things. They are all composed of a substance called protoplasm, and this protoplasm is always organized in units known as cells. A single cell is so small it cannot be seen with the naked eye. There are many kinds of cells, which differ in their appearance, but the protoplasm is essentially the same in all. It is the protoplasm that performs all essential life functions. In so doing, it is gradually destroyed, but it builds itself up as fast as it is torn down. The term metabolism is used in a narrower sense for this self-destruction and renewal, as well as in a wider sense for the similar process by which the whole organism maintains itself. Protoplasm and life are very intimately related. Nothing whatever except protoplasm is living, and as soon as protoplasm ceases to live it ceases to be protoplasm.



(Courtesy American Museum of Natural History, New York)

Fig. 57. This drawing shows a small group of plant cells very much enlarged. Notice the cell walls, the protoplasm, and the nuclei. Is there more than one nucleus in any cell?

THE CELL

Though a cell is so small that it can be seen only with a microscope, it is a very complicated affair. There are three main parts to every cell. On the outside is the cell wall. This may be anything from a fine thin membrane to a thick woody covering. Inside the cell wall is the protoplasm. This consists of a thick liquid with various sorts of solid granules (little grains) and vacuoles (droplets) of

other liquids floating about in it. Somewhere within the protoplasm, and forming a part of it, will be found the nucleus of the cell. The nucleus is very important. Its character determines the structure of the cell and it is through the nucleus that the features of the cell are transmitted in the reproduction process so that cells reproduce others of their own kind.

The simplest organisms consist of single cells. The higher animals and plants consist of groups of cells banded together to perform their functions more efficiently. Some of the cells specialize in one function and some in another. Large groups of cells become associated in organs, and sometimes each organ does only a single thing. But as long as each cell is alive it continues to do, on a small scale, all the main things, that the organism as a whole does on a large scale. To illustrate the working-out of these processes, we shall consider some organisms which live their whole lives as single cells. The great majority of all living things, indeed, are one-celled. We do not see them because they are so small.

Protozoa, or One-Celled Organisms

The Amoeba

This organism lives in stagnant pools and ponds. It is easily seen in a low-power microscope, and appears as a jelly-like mass of more or less irregular and constantly changing shape. From time to time an extension pushes out from the main body, a sort of arm. More and more of the protoplasm flows into the arm, until it becomes larger than the body, which is now only a sort of tail. Finally this is drawn in and we discover that the amoeba has moved. This is his only method of locomotion. But this description of the process is really too simple. As a matter of fact, the amoeba is often pushing out several arms in different directions at the same time. If one of the arms encounters a food particle it simply divides, surrounds the particle,

and closes. The particle is then inside the amoeba, and we may say the particle has been "eaten."

Waste materials collect in droplets or vacuoles in the protoplasm, and these vacuoles are pushed out of the cell in a fashion much like the reverse of the "eating" operation. When one of these vacuoles has been pushed completely out, the amoeba simply goes away and leaves it.

(Courtesy F. E. Lloyd)

Fig. 58. This is what an amoeba looks like when viewed through a high-powered microscope. Notice the granular appearance of the protoplasm. Can you discern any vacuoles?

If the amoeba is touched by something hard, it will move away. If it is placed in a shadow it will move toward the light. As the amoeba eats it grows larger. When it gets to a certain size, the nucleus splits in two, and the halves go to opposite ends of the cell. The central part of the cell now draws in until the amoeba looks like an hour-glass or a dumb-bell. Finally the two parts separate, and there are two organisms. This is the simplest method by which reproduction ever takes place. Since each of the parts is a complete organism, the amoeba never dies a natural death.

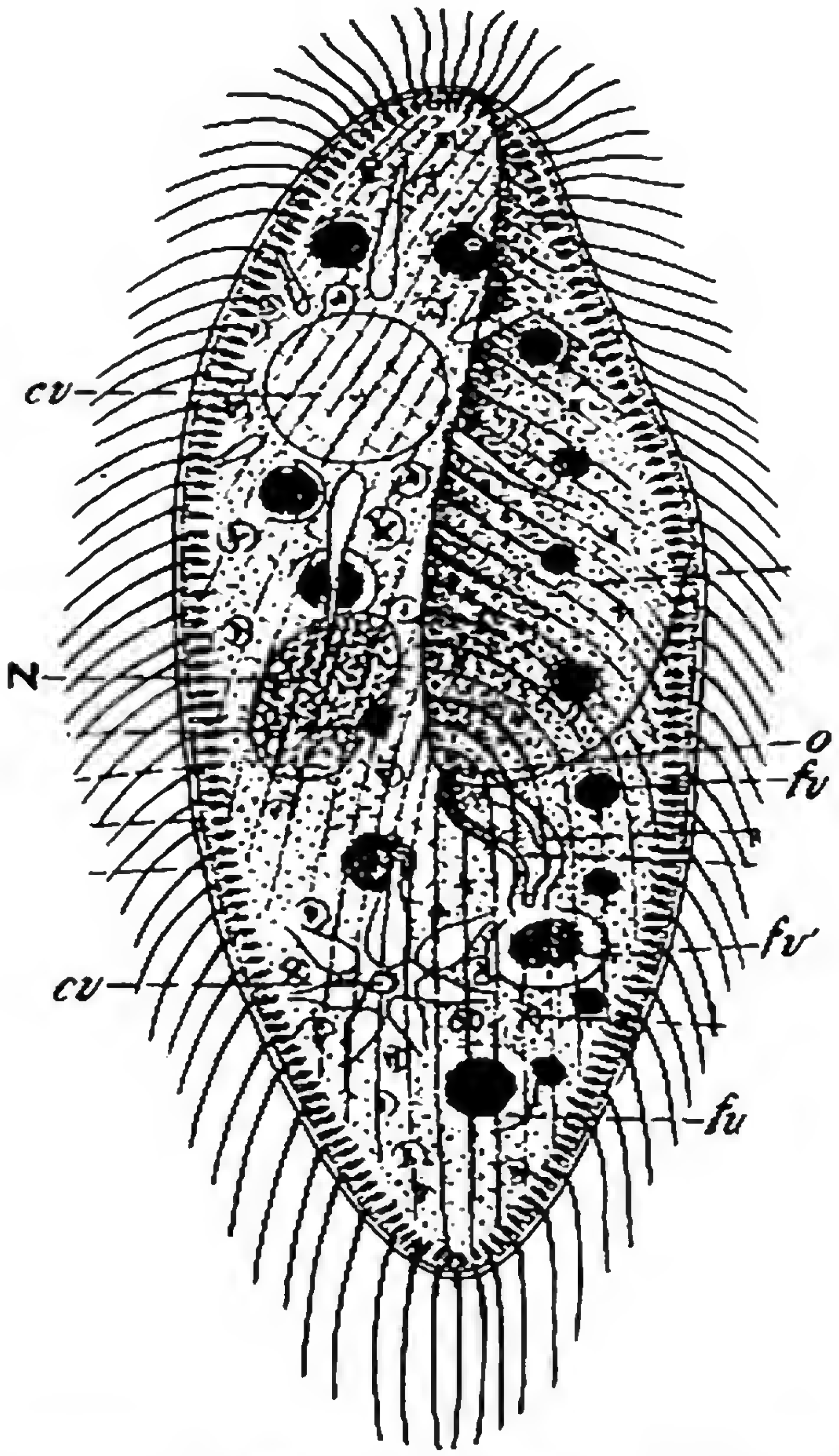
The Paramecium

This little organism consists of a single cell. It is somewhat larger than the amoeba, and unlike the amoeba, it has a definite shape. Near the middle of one side is an opening that serves as a mouth. Around the edge of this opening, as well as everywhere else over the entire body, are a great number of small hairs, called cilia. With the cilia around the mouth opening, the paramecium sweeps food particles into the opening. The cilia covering the body make

rhythmic beating movements, and enable the paramecium to swim about. Paramecium has no special area for breathing. Oxygen dissolved in the water is absorbed through the cell wall everywhere on its surface.

Paramecium reproduces, just as does the amoeba, by dividing into two sections, each of which becomes a complete organism. It seeks the light, swims around obstructions, and exhibits many other simple reactions in response to changes in its surroundings.

These two one-celled organisms illustrate life processes as they are carried on by very simple forms of both plants and animals. The more elaborate and complex forms of plants and animals, such as we know in everyday life, carry on these processes in more complicated ways. And the plants carry on the processes in ways somewhat different from the ways of animals.



(Courtesy American Museum of Natural History, New York)

Fig. 59. Drawing of a paramecium, very much enlarged. The mouth-opening is shown at o. Food vacuoles are shown at fv. Two special vacuoles for waste excretion are shown at cv. N is the nucleus. Notice the cilia everywhere on the body.

Animals and Plants

Most people know, in a general way, the difference between an animal and a plant, just as they know the difference between a living thing and one which is not alive. But there is no single feature that definitely distinguishes plants from animals, and there are some simple organisms which

are difficult to classify either as plants or as animals. The amoeba is one of these, though most biologists agree that it is more an animal than a plant.

Most animals are able to move about, and most plants are not. But some animals grow attached to the rock for their whole lives, and some very simple plants are able to move about. Most plants are able to build their own foods from the inorganic, or non-living, materials.

All animals must eat plants or other animals. This is the most important distinction between animals and plants. But as we shall see later, there are many plants which must get their food from other plants, and even in some cases from animals.

In most plants, the cell walls are thick and solid. In animals, most of the cell walls are thin membranes.

In most plants, growth in length occurs only at the ends of branches and roots, and this growth continues throughout the life of the plant. In most animals, growth in length occurs throughout the organism, and growth stops long before death occurs. But there are exceptions to every one of these rules.

Classification of Plants

Plants may be classified on the basis of how complicated they are, the lower forms being very simple, and the higher forms very complicated. On this basis, the protozoa and the bacteria are the simplest. We have already seen how simple in structure the protozoa are, and we shall examine bacteria a little later. The algæ, which we shall also study, are somewhat more complicated than the protozoa and bacteria. Next in order come the fungi, which include mushrooms, toadstools, and the like. They do not have the green color characteristic of most plants, but they are plants, nevertheless. Mosses are the next step, and are followed by ferns, which are still higher types. Conifers, of which the spruces and pines are examples, are still higher

forms. Finally, the greatest complication is found in two groups: one known as the monocots and the other as the dicots. The monocots include all plants like grasses, lilies, and palm trees, and the dicots include such plants as roses, daisies, and oaks. Monocots and dicots are distinguished from each other by certain characteristics in their seeds.

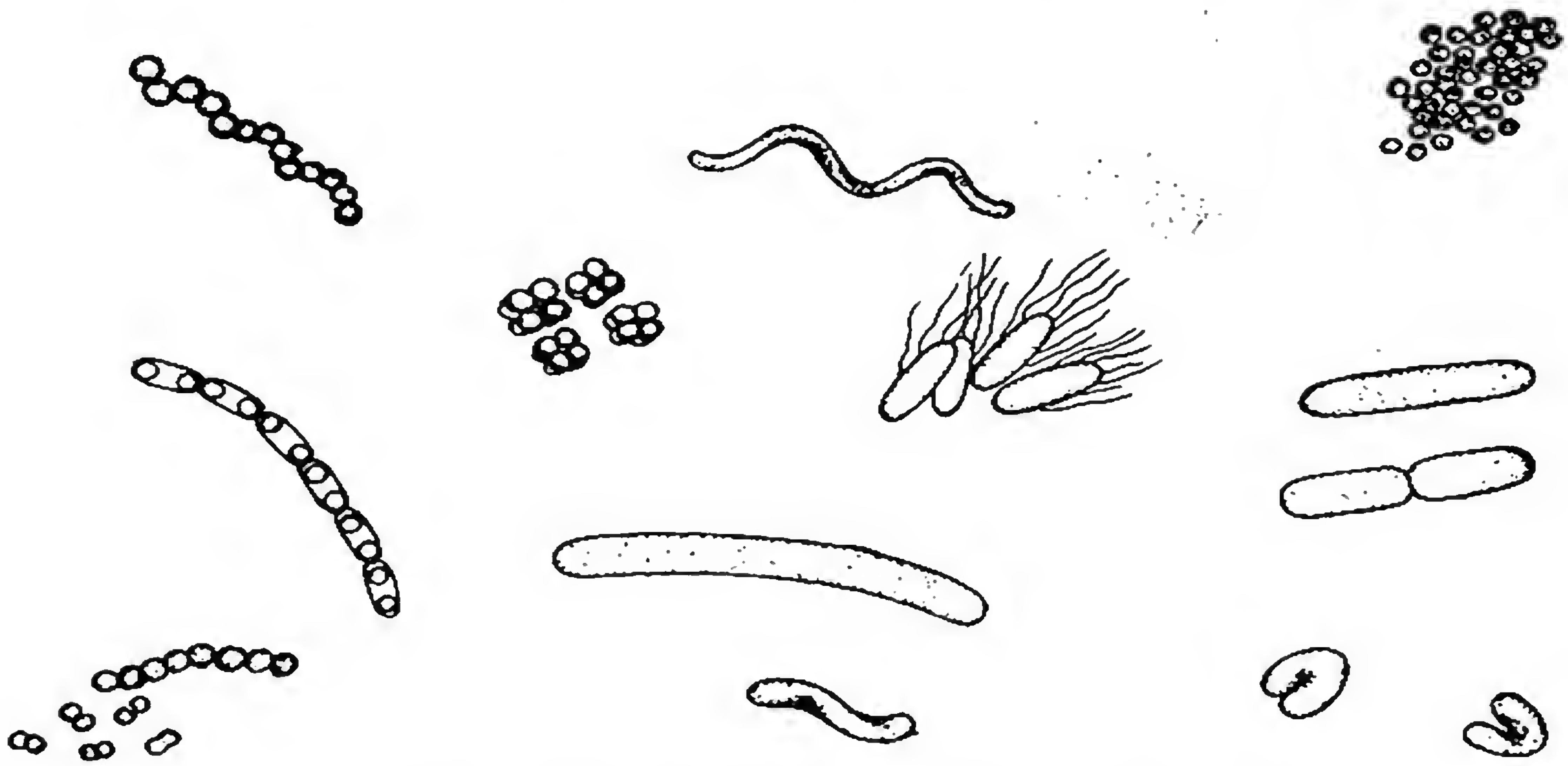
We may summarize this classification in the following table, in which the lower, simpler forms appear at the bottom, and the higher, more complex forms, at the top.

Name of Group	Example
Monocots and Dicots	*Monocots:* grass, lily, palm tree *Dicots:* rose, daisy, oak tree
Conifers	Pine tree, spruce tree
Ferns	Ordinary ferns
Mosses	Ordinary tree moss
Fungi	Toadstools, mushrooms, yeast
Algae	Sea weed, stringy pond scum
Bacteria and Protozoa	*Bacteria:* those of typhoid fever, cholera, boils *Protozoa:* amœba

Nutrition in Plants

Plants can also be classified by the methods they use in getting food. Many simple forms get their food from other living plants or animals. These are called parasites. From the point of view of mankind the most important of the parasites are certain bacteria. These are one-celled plants, much smaller even than the amœba. They can be seen only with the best microscopes, and many of them cannot be seen even then. They cause disease by eating the living cells and by excreting poisonous wastes. Other parasites, called fungi, attack plants. The mildews, smuts, and

rusts are fungi of this type. These plants are composed of many cells, but they are still rather simple. The cells do not assume special functions to any very great degree. It is interesting to note that the bacteria attack animals mainly, while the higher fungi attack principally plants.



(From student drawings, Department of Botany, Harvard University)

Fig. 60. Various kinds of bacteria, very much enlarged. Nearly every one of those shown is the cause of some disease in man. All of them are parasites.

The mistletoe, which lives on certain trees, is one of the highest types of parasite. Its cells are specialized, and it grows to a considerable size.

Some plants get their food from dead plants and animals. The bacteria of decay and putrefaction are of this type. So also are the molds and yeasts and many other fungi, among them the mushrooms, toadstools, and puffballs.

The great majority of plants manufacture their own foods. They are able to take carbon dioxide from the air and combine it with water to form starch, sugar, and other important materials. This process takes place in cells which contain the substance chlorophyll. It is chlorophyll that gives most plants their characteristic green appearance. In

(Courtesy U. S. Department of Agriculture)

Fig. 61. These wheat stalks have been attacked by a fungus, Black Rust. The rust is a plant, just as much as the wheat is. But the rust is a parasite, drawing all its nourishment from the wheat. This is an example of a harmful parasite.

the presence of chlorophyll, the energy of the sunlight is able to build up starch and other carbohydrates from inorganic materials. This property makes the green plants the most important of all living things, for in the end they form the basic food supply of other types of plants and of all animals. Green plants could live in a world that contained no other form of life, but if the green plants were to die, all other forms of life would perish with them.

Plant Forms

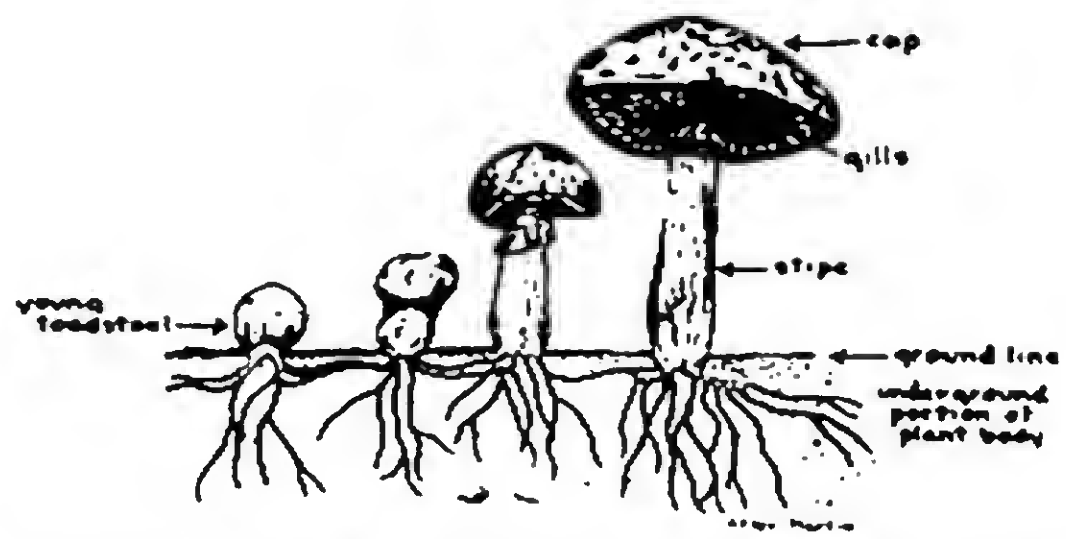
The simplest of the green plants are the algæ. These are often one-celled, but some algæ have millions of cells, which are specialized in function to a considerable degree. In the ocean, there are millions and millions of free-floating one-celled algae. These form the basic food-supply of all higher marine life. The ordinary green scum seen on stagnant ponds is one form of algæ. The fine strands of this scum are each composed of a single string of cells. The largest of the algæ is the giant kelp or sea-weed of the Pacific

coast. Practically all algæ live in the water.

The next higher types of green plants are the mosses. These are able to live on the land, but they must remain in damp places, if they are to grow luxuriantly. They have a layer of hard cells on the outside which prevents their losing too much water by evaporation, but their root structures are such that much moisture is needed for them to provide the plant with water.

They must therefore live close to a fairly abundant supply. One of the mosses is of some economic importance. It lives in bogs, and after it dies it decays and forms peat, which is a valuable fuel, although only in certain parts of the world. There are many people who have never seen peat burn.

The ferns have more efficient roots than the mosses do. They can therefore live in regions which would be too dry for mosses, but they still require a fairly moist atmosphere. They grow mostly in damp regions or under trees that keep the



(Courtesy U. S. Department of Agriculture)

Fig. 62. Successive stages in the growth of a toadstool. This plant has no green coloring and cannot make its own food, but must get it from decayed organic material in the soil. If there is no decayed organic material in the soil—then what?

(Courtesy F. E. Lloyd)

Fig. 63. Microphotograph showing a protozoön eating an alga. Several strands of algae are shown. The strand in which the spiral coloring is missing has been attacked by the protozoön, shown fastened to it. The dark masses in the body of the protozoön are the remains of the colored spirals of the alga, now being digested.

sun from drying them out. In the tropics some of them become as large as small trees.

Most of the plants we see are of types higher than the algæ and mosses and ferns. The so-called "higher plants" include the grasses, trees, and flowering shrubs. One or another of them is able to live in nearly any sort of climate.

(Courtesy Harvard Botanical Museum)

Fig. 64. Tree ferns growing in a tropic jungle. Some tree ferns grow even larger than these. It is in such warm, moist places as this that we expect to find the lower forms of plant life flourishing.

Their roots absorb water from the soil, and their green leaves build up food under the action of sunlight without losing too much water by evaporation. All the important agricultural plants belong to this group.

Experiment 10. Bring to school specimens of algæ (pond-scum), moss, ferns, and flowering plants. Examine these carefully. Notice the greater complexity of the higher plants. Observe the root hairs and leaves of the ferns and flowering plants through a microscope, or through an ordinary magnifying glass. Many interesting observations can be made with a simple pocket lens.

The Processes of Metabolism in the Higher Plants

Though the higher plants differ enormously in size and appearance, they all have the same basic functions, and the same corresponding structures. When the seed of such a plant first starts to grow we see the two principal parts. These are the root, which grows down into the ground, and the shoot, which grows up into the air.

Special Plant Parts

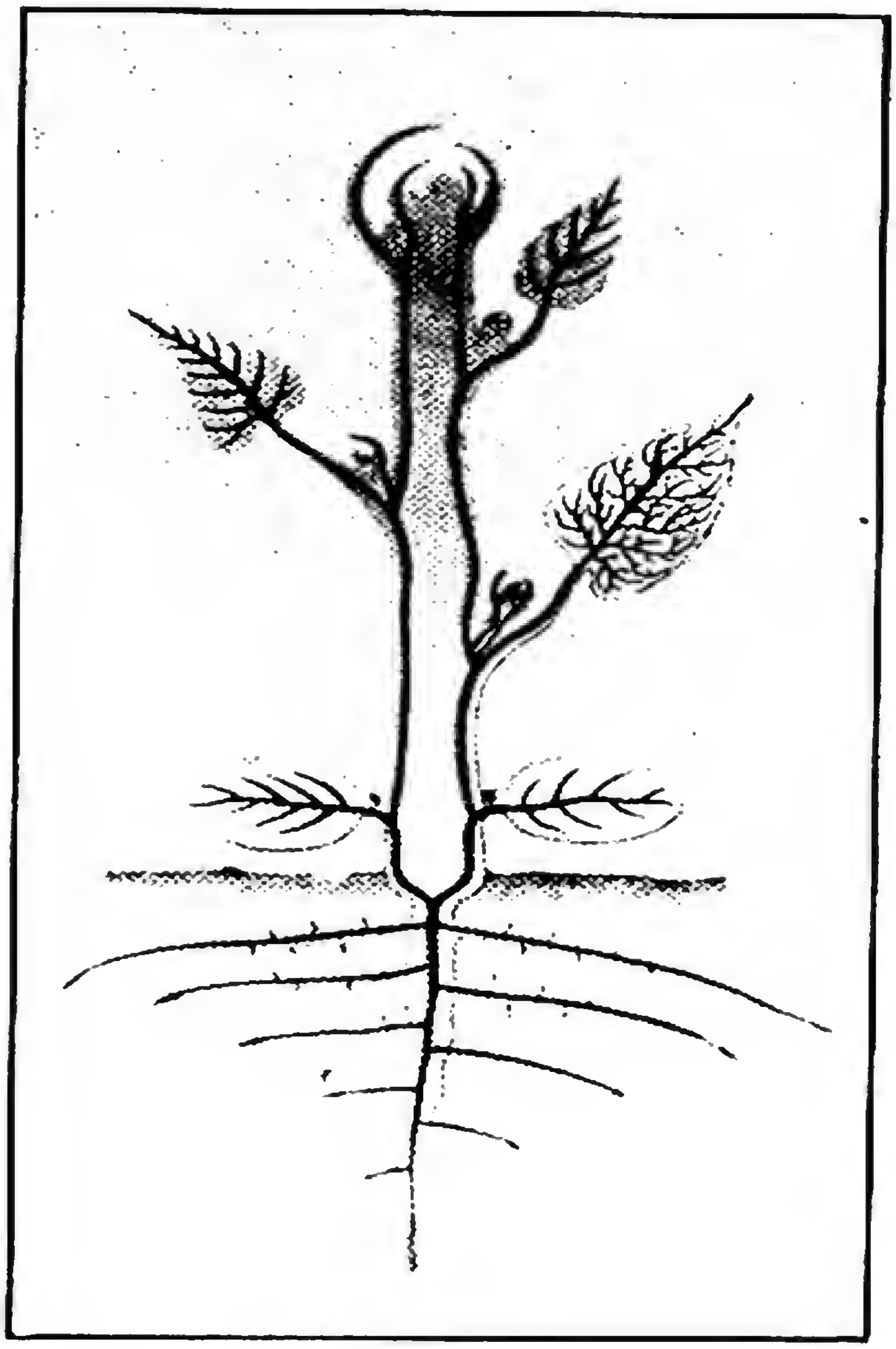
The root of a plant serves to anchor it in the ground and support it. It also performs the much more important function of absorbing water and minerals from the soil. Some roots grow straight down. Others branch out in all directions. Still others are rounded and bulbous, like the sweet potato, and perform the additional function of food storage. The most important parts of the root are the small root hairs. Each root hair is a part of a single cell. The root hairs grow out into the soil and absorb water and dissolved minerals through their cell walls. The water and minerals are used by the plant for food.

(After Sachs, courtesy U. S. Department of Agriculture)

Fig. 65. Diagram of a root-hair in the soil, very much enlarged. The dark areas are particles of soil. The white areas are air-bubbles. Wavy lines in the soil indicate water. In growing, the root-hair forces its way in between the grains of soil. Why should garden soil be both loose and moist?

The shoot of a young plant soon develops into three parts: the stem, the leaves, and the flowers. The stem serves to support the leaves and flowers and to connect them with the roots. Water and minerals are brought from the roots through the stem to the leaves and flowers, and food from the leaves is taken to the flowers and roots. The movement of the sap, which carries all these things, is very slow. A given part of the sap may take hours to travel from the roots to the leaves of a tree.

In the larger plants, such as trees, the cells of the stem grow very thick walls. Finally the cells die, and in some trees these dead cell walls harden and become stronger still. Only the outer layers remain alive. These layers are called the sap-wood. The dead inner layers are called the heart-wood. It is the heart-wood that gives the trunks and branches of trees their great strength.

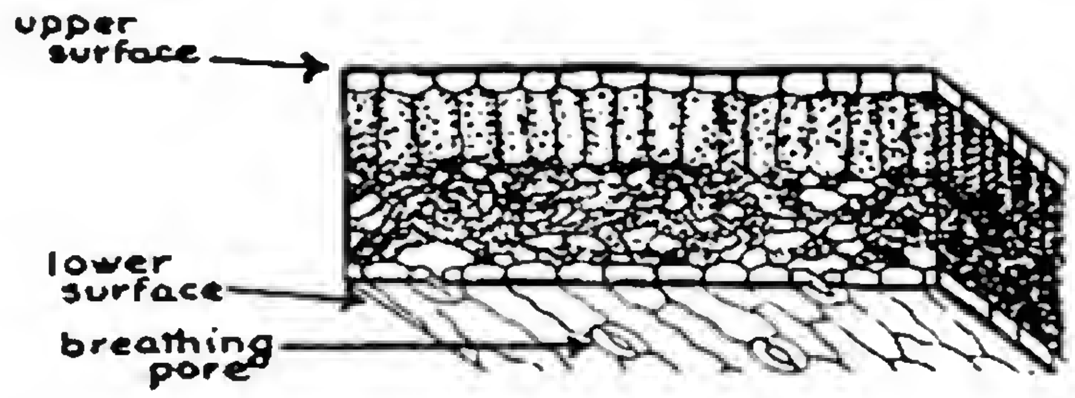


(After Sachs, courtesy U. S. Department of Agriculture)

Fig. 66. This diagram shows how a plant grows, and how the parts work together. At the bottom of the stem are the two first leaves, which appear very early in the life of the plant. At the very top are leaves which have not yet opened out. The double dark line running up and down the plant indicates that the roots provide materials for the upper parts of the plant and the leaves provide food which is carried to all parts of the plant, including the roots.

The leaves of trees contain the green chlorophyll. Under the hard outer layer of cells that prevents too much evaporation, the green cells are at work all the time that the sun is shining on them. They take carbon dioxide from the air and water which the roots have taken from the soil. In the presence of chlorophyll these are combined by the energy of the sunlight into starch, and oxygen is given off. The starch may change into sugar or cellulose. Cellulose is the main material of the woody cell walls. It is found in a very pure state in cotton. Starch and sugar combine with oxygen and minerals from the soil to form one of the important parts of the living protoplasm.

Experiment 11. Boil a few grains of corn starch in a test tube or a small pan of water. Cool and add a drop of tincture of iodine. The characteristic blue-black color is a test for starch. Obtain a potted geranium. Set outside in the sunlight. Pick a leaf from the geranium. Boil some water in a pan, and then turn out the flame. Dip the leaf in the hot (but not boiling) water for about a minute. Then dip it in a pan or bottle of alcohol. The green chlorophyll should dissolve, leaving the leaf white or gray or tan. Dip the leaf into some water to which has been added a little iodine, and see if it turns blue-black. Put the plant in a dark closet for two days. Pick another leaf, remove the chlorophyll, and repeat the test for starch.



(Courtesy U. S. Department of Agriculture)

Fig 67. This cross-section drawing shows that a leaf is really a fairly complicated structure, even if it does seem thin and flimsy. The board-like row of cells and the layer of cells underneath it perform, by means of the little round corpuscles contained in them, the manufacturing processes of the plant (photosynthesis). Note also the breathing pores and the layers of cells at the upper and lower surface. These layers prevent evaporation from carrying away too much water from the plant.

Experiment 12. Water the geranium well. Set it in the bright sunlight for an hour or two. Then cover it with a bell-jar and leave it for another hour. Light the end of a small splinter of wood 6 or 8 inches long and let it burn a few seconds. Blow out the flame, leaving a glowing coal on the end of the stick. Thrust this coal inside the bell-jar, moving the jar as little as possible in order to do this. If the coal becomes brighter or bursts into flame the presence of oxygen is indicated. Repeat the experiment with the same plant after it has been kept in the dark for two days, keeping it fairly dark through the experiment.

Experiment 13. Water the geranium and let it stand until no more water drains from the bottom. Wrap the pot in paper, tying it around the stem carefully. Wipe the inside of the bell-jar dry, cover the plant with it, and leave in the sun for an hour. Drops of water, which must have evaporated from the leaves, should condense on the inside of the jar.

Respiration

Respiration goes on in every living cell. Oxygen combines with starch or sugar or fat or protein, and carbon

dioxide is given off. At the same time, energy is set free. It is this energy that is used by the plant to carry on the life processes. The energy comes from the oxygen and from the food.

The process by which plants build up food materials is called photosynthesis. This process is in a way the opposite of respiration. We shall show in a table a few of the main differences.

RESPIRATION	PHOTOSYNTHESIS
Sets free energy	Uses up energy from the sun
Sets free carbon dioxide	Uses up carbon dioxide
Uses up oxygen	Sets free oxygen
Uses up food	Builds food materials
Goes on all the time and in every cell of the plant	Goes on only in the green cells of leaves and only while light is shining on the leaves

Respiration goes on at the same rate day and night. Photosynthesis goes on in the daytime only, but while it is going on it is a faster process than is respiration. As a result, leaves in the daytime use up all the carbon dioxide produced by respiration and more too, which they get from the air. Oxygen is supplied for respiration, and some in addition is given off into the atmosphere. At night or in the dark, photosynthesis stops, and the same plants use up oxygen from the air and give off carbon dioxide. A green plant will die from lack of nutrition if kept in the dark.

Not all the water which the roots absorb is used to build food. Much of it evaporates in spite of the protecting outer layers of leaves and stems. This evaporation is necessary, as otherwise the plant would soon become full of water, and no more dissolved minerals would be brought up from the roots. It also prevents the plant from becoming too hot and withering in the hot sunlight.

The Flower

The flower has no important function in the process of nutrition. It is concerned only with the reproductive function, and since that function will be studied later, the flower

need not be considered here. The individual plant could live its life just as well without flowers as with them.. Without them, however, it could not reproduce its species on the Earth.

Questions for Review, Discussion, and Study

Chapter IV

1. Just what do you mean when you say a dog is alive and a rock is not?
2. If you lose your hand, you do not grow a new one. Does this hold for the loss of a finger? For the loss of a patch of skin? Of a fingernail?
3. The text says living things adapt themselves to their surroundings. Does this mean that if you lived in the far north you would grow a body-covering of hair?
4. What do we mean by an "organ" of the body? What are the organs of sight? Of hearing? Is the heart an organ? The stomach?
5. What do we mean by a "natural death?" What other kinds of death are there?
6. Consider the sentence, "the amœba never dies a natural death." Does the sentence mean that the amœba you see in your microscope will never die unless killed?
7. Most people think plants live their whole lives in one place, while animals move about. Can you give an example of an animal which does not move about at all?
8. How can you be sure that plants existed on the Earth before animals did?
9. Can you find the word "monocot" in the dictionary? How about "dicot?" What very similar words do you find?
10. Do plants have diseases?
11. What do you mean by "specialized cells?" In what way are bone-cells specialized? Nerve-cells?
12. Is yeast a plant or an animal? Does yeast give off carbon dioxide? What use is made of this property of yeast?
13. If there were only one sort of living thing on the Earth, what sort would it be?
14. Why don't you very often find ferns or mosses growing on open sunny hillsides?
15. Where do you find the root-hairs of the radish plant? Of the turnip?

16. Is the sap of any tree ever used for food? What other uses do we make of plant saps? How about rubber? Turpentine?

17. If you wanted to be sure all the starch was washed out of a piece of cloth, how could you test it?

18. Why does a plant need food to produce energy, when it doesn't move about?

19. Why should you keep plants in the livingroom and not in the bedroom?

20. In what sense could you say that a green plant kept in the dark would starve to death?

CHAPTER V

ANIMALS AND THEIR FUNCTIONS

Life Functions in Animals

Animals are composed of cells containing protoplasm, just as are plants. Some animals consist of single cells, and others are made up of millions of cells, which are very highly specialized in structure and function. The three basic functions—metabolism, growth and reproduction, and irritability—are found in all animals just as they are found in all plants. Most animals are more complicated than most plants. Animals are able to move about, and as a consequence the function of irritability is much more prominent in them than in plants, as the movements must be directed and adjusted to changes in the environment.

In the last chapter we saw how two very simple forms of life, the amœba and the paramecium, went about the process of living. We saw how they moved about, took in food, breathed, gave off waste matter, grew, and reproduced. These one-celled organisms exhibit, in their small way, the functions of all living things. The more complex forms of organisms perform the same functions. We have also seen how one kind of higher organism, the plants, carry on these functions. We shall now see how the other sort of living things, the animals, go about performing the same functions.

Classification of Animals

Just as plants may be classified on the basis of their complexity, so may animals. Such a classification would begin with the simplest living things,—the protozoa—which display characteristics of both plants and animals. Next come the sponges, which, while they live all their lives in one place, are nevertheless animals. The coelenterates,

which include such animals as the sea anemone and the jellyfish, are more complex than the sponges. Next in

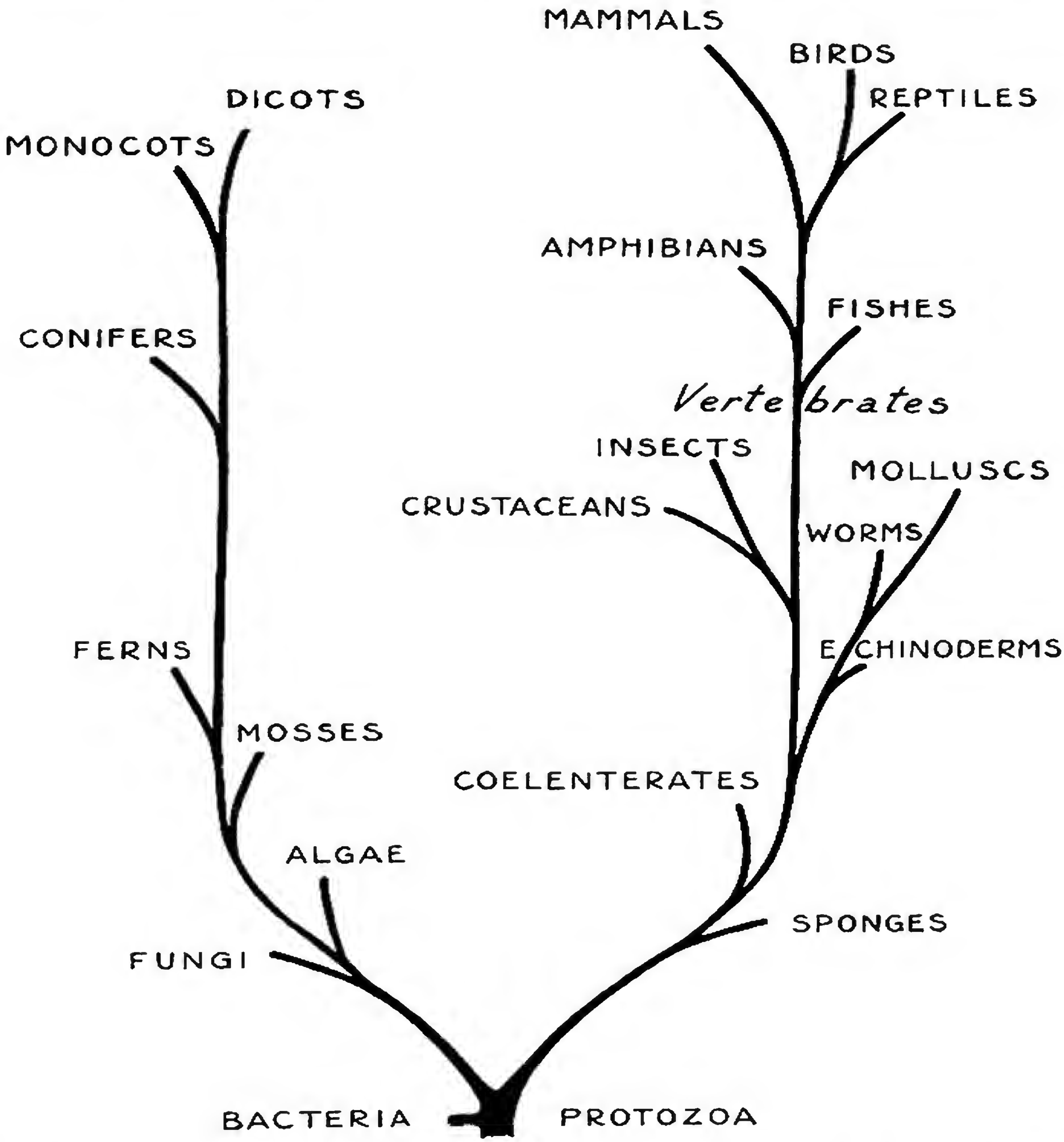


Fig. 68. On the left of this diagram is an outline of plant classification. On the right is the corresponding classification of animals. Note that Protozoa are incluled in both sides.

order of complication come the echinoderms, of which the starfish, the sea urchin, and the sea cucumber are examples.

The worms are next in order. The crustaceans are still more complicated. These include such animals as the shrimp, the crab, and the lobster. Still more complex are the molluscs. These include the clam, the oyster, the snail, and such animals. The insects are even more complicated than the molluscs.

All the animals mentioned so far are invertebrates; that is, they do not have backbones. The vertebrates are more complicated, and hence "higher" animals than the invertebrates. The vertebrates, or back-boned animals, are as follows: Least complicated, but still more complex than any invertebrate, are the fishes. Next come the amphibians, which include frogs, toads, newts, salamanders, and the like. Then come reptiles, which include lizards and turtles as well as snakes. Birds are of a still higher type than reptiles. At the top of the list stand the mammals. This highest group includes many familiar animals, such as pigs, dogs, cats, horses, cows, deer, wolves, sheep, monkeys, etc. Not everyone knows that the whale is a mammal, and belongs to this highest group, not down with the fishes. Man also belongs to this group. He is, in fact, the highest type in this highest group.

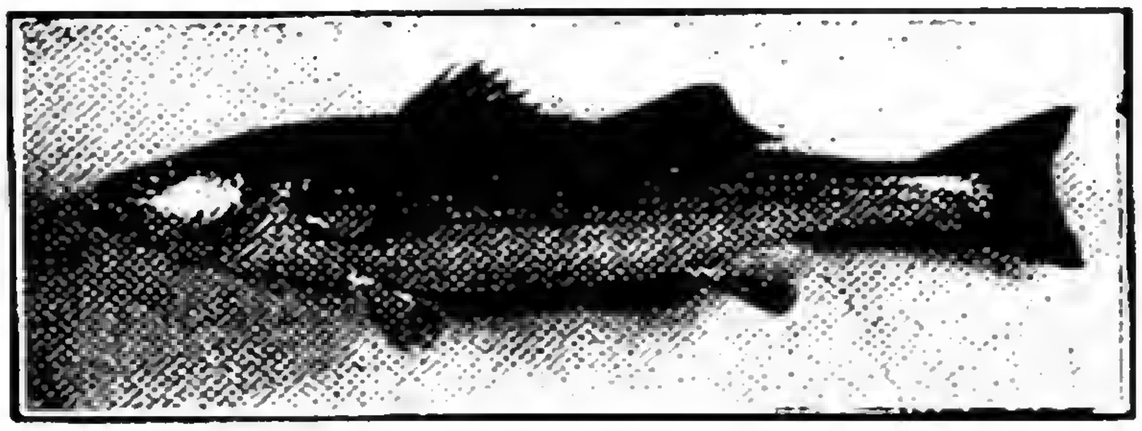
Metabolism in Animals

Metabolism in animals is simpler in some ways, and more complicated in others, than it is in plants. All animals must eat food obtained from the bodies of plants or other animals. None are able to build up their own foods as are the green plants. Hence the food-getting abilities of animals depend to some extent on their powers of locomotion.

Some animals, such as fleas, ticks, and lice, live as parasites upon living plants or other living animals, without destroying the organism they live upon. Others live upon dead plants and animals. Some of these, which eat only plants, are called herbivorous. The cow is a familiar example. Others, such as wolves and toads, eat only animals, and are called carnivorous. Still others, which eat both

plants and animals, are called omnivorous. Chickens and human beings are examples of omnivorous animals.

Most animals need much more food than do most plants, because the animals use up much more energy in moving about. For the same reason, they often require much more oxygen. Most animals have a complicated breathing apparatus to get the oxygen from the air or water, and a complicated system of circulation to deliver it to the cells. This circulatory system also serves to remove the waste products from the cells and deliver them to the special organs of excretion.



(Photo by Boston Museum of Natural History)

Fig. 69. Compare the strength of the tail structure with that of the fin structure in this striped bass. Which appears to be more effective in bringing about forward motion?

We shall consider the three functions, locomotion, food getting, and breathing in further detail.

(Courtesy American Museum of Natural History, New York)

Fig. 70. Locomotion in the sea-star. Can you discern the tube-feet on any of the animals? Do you see any evidence to show that the sea-star's body is flexible?

Experiment 14. Bring specimens of snails, insects, worms, starfish if possible, frogs, and other small animals of the lower types to school.

Observe carefully how they make their way about. Feed each one with the appropriate kind of food and note how he eats it. See whether you can examine the breathing apparatus of each. See if you can tell what sort of a circulatory system is possessed by each.

Locomotion

We have noticed how the paramecium moves about in the water by means of beating hairs or cilia. Sea worms and eels, as well as snakes when in the water, swim by wriggling their bodies. A series of waves passes back from the head to the tail, and the animal as a consequence moves forward, often with great rapidity. Fish swim with their fins and tails. The side-to-side flapping of the tail is often much more important as a source of power than is the movement of the fins. The flying fish has very large fins. Gaining speed in the water, he is able to shoot into the air from the crest of a wave and sail along close to the water for a hundred yards or more.

(Courtesy American Museum of Natural History, New York)

Fig. 71. Notice the way the crab's legs are pointed. Does this structure lead you to expect him to run sideways? The small crab in the background is approaching.

A great many animals move only on the bottom of the ocean or on the surface of the land. Though they differ greatly in appearance, the basic principle of locomotion is always the same. Part of the body is lifted, moved forward, and fastened. The main body is drawn or pushed ahead, the first part or some other portion is again extended and fastened, and the process is repeated.

The starfish has many little tube-like feet with which he sucks fast to the rock surfaces. He loosens some of these, moves them a fraction of an inch, and then fastens them

again. After that he moves others, and so makes his way slowly along. Many other animals that live in the sea have suckers on their feet. Their weight is not enough to hold them down while walking on the bottom.

Crabs, lobsters, and shrimps are exceptions to this rule. Their shells are heavy enough to keep them on the bottom while they walk along on their ten legs. Crabs are odd in their movements. They walk sidewise instead of forward.

(Courtesy American Museum of Natural History, New York)

Fig. 72. Two sea anemones. Note the closeness with which their feet adhere to the rock. Do these animals have any means of locomotion at all?

The sea anemones and many of the shellfish have only a single sucker foot. With this, they fasten themselves to a rock and stay for long periods. Some live their whole lives in one place. Others loosen themselves from time to time and drift around until they find another suitable place to fasten themselves.

Animals that live on the land nearly all depend on their weight to hold them down, and have no suckers on their feet. Some do not have true legs or feet at all. Thus worms move by lengthening some parts of their long tubular bodies and shortening others. The lengthening is always done by lifting and stretching forward, and the shortening is always done by drawing up the rear parts of lengthened sections. In this way the worm moves slowly forward. The snail moves in somewhat the same manner. As his one large flat foot rests on some surface, a series of small waves passes from the back to the front along the bottom of the foot. Snakes move by wriggling their bodies in a series of waves. They cannot shorten and lengthen different sections as can worms, for they have backbones which prevent this. Their backbones are flexible, however,

and they are able to move much faster than snails and worms, though they are still noticeably slower than are the animals which have legs.

Most land animals have legs. There may be almost any number. The centipedes have thirty to sixty legs, and the millipedes even more. Insects all have six legs. The majority of the larger animals have four, but in many cases their front legs are used for purposes other than walking. The wings of birds and bats are specialized types of forelegs. So also are the arms of the monkeys and of man. The wings of insects are of a different type, and all winged insects have their six legs in addition to the two or four wings by means of which they fly.

Fig. 73. Looking through a glass plate at a snail which is crawling up the other side. Note the waves in the snail's foot. Do these waves move up faster than the snail does? See text.

Food Getting and Eating

We have already seen that the amœba takes in food particles by surrounding them and that the paramecium has a sort of mouth, or opening to the interior of the cell, into which the surrounding hairs or cilia drive food particles. Each of the higher animals has some sort of a digestive organ, with a definite mouth which is usually able to open and close. This digestive cavity is the most elementary specialized organ. It is found in animals that have practically no other special organs. Thus the sea anemone has a single body cavity with an opening at only one end of the cavity. Around the edges of the opening are tentacles, with which the sea anemone catches small animals and puts them in the opening. The cells on the inside of the cavity give off juices which digest the food. Many other and more complicated animals of the sea have a central mouth opening

and digestive cavity, with the other organs radiating from these. Among these are the starfish and the squid. The squid has ten long tentacles covered with suckers, with which he seizes small animals. He also makes some use of these tentacles in swimming.

The higher animals nearly all have a rather long body with a definite head at one end. The head contains the mouth, which in most types is more than just an opening to the digestive tract. In frogs, ant-eaters, and certain other animals, there is a long flexible tongue, which is covered with a sticky substance and is used in licking up insects and other small animals used as food. A great many animals have some sort of apparatus with which they crush their food before swallowing it. The insects have special mouth parts for this purpose, while some fishes, some lizards, and all the higher land animals or mammals, have teeth.

(Courtesy American Museum of Natural History, New York)

Fig. 74. The frog in the background has the tongue extended as in licking up an insect. The one in the foreground has picked up his prey and is about to close his mouth upon it. Do you suppose this tongue action is very rapid?

Most animals have special structures which help in securing food. Many have stingers or fangs with which they paralyze their prey. The jellyfish, which is a very simple animal, has stingers. Bees, wasps, and many other insects have a stinger on the back end of the body. Some snakes have poison-bearing fangs in their mouths. Crabs and lobsters have large nippers with which they seize their prey, and a great many of the carnivorous mammals are equipped with claws, fangs, or horns.

Snakes which do not have poison fangs often kill their prey by coiling their bodies about it and squeezing it to death.

We all know that the beaks and bills of birds are specially adapted to the foods they eat. Those which eat insects have long bills, while those which eat seeds have short strong beaks.

Squirrels, kangaroos, and a number of other animals use their front feet to hold food while they eat it.

The body structures which animals use in getting their food and eating it are many and varied, but they all serve the same purpose. Each animal has a food-getting and eating apparatus which is adapted to the kind of food he eats. Or perhaps the truer statement may be that he eats the kind of food he is able to get with the structures provided by nature.

Fig. 75. The gills of the tadpole are prominent but not very complicated. What advantage is there in the form of the gills?

Breathing and Respiration

Respiration is a fundamental activity that goes on in every living cell. In order for respiration to take place there must be a way of getting oxygen to the cell. Oxygen makes up about one fifth of the air, and considerable quantities of it are dissolved in water. The simpler animals, such as the amœba and paramecium, absorb oxygen directly through the cell walls. The more complicated forms must have a special breathing apparatus to extract the oxygen from the air or water, and a circulatory system to distribute it to the cells. In the process of respiration, carbon dioxide is generated. In one-celled animals and in plants, this passes out directly through the cell walls. In higher animals the circulatory system brings the carbon dioxide to the lungs or gills, from which it is eliminated.

All the animals which live in the water, except the very

simplest, have gills. These must consist of some sort of finely branched structure so that they may expose a large surface area to the water. Inside the branches flows the blood or body fluid. Movement of one sort or another causes the water to flow over the gills. The cells which line them extract the dissolved oxygen and pass it on to the blood. These cells also take the carbon dioxide from the blood and pass it back into the water.

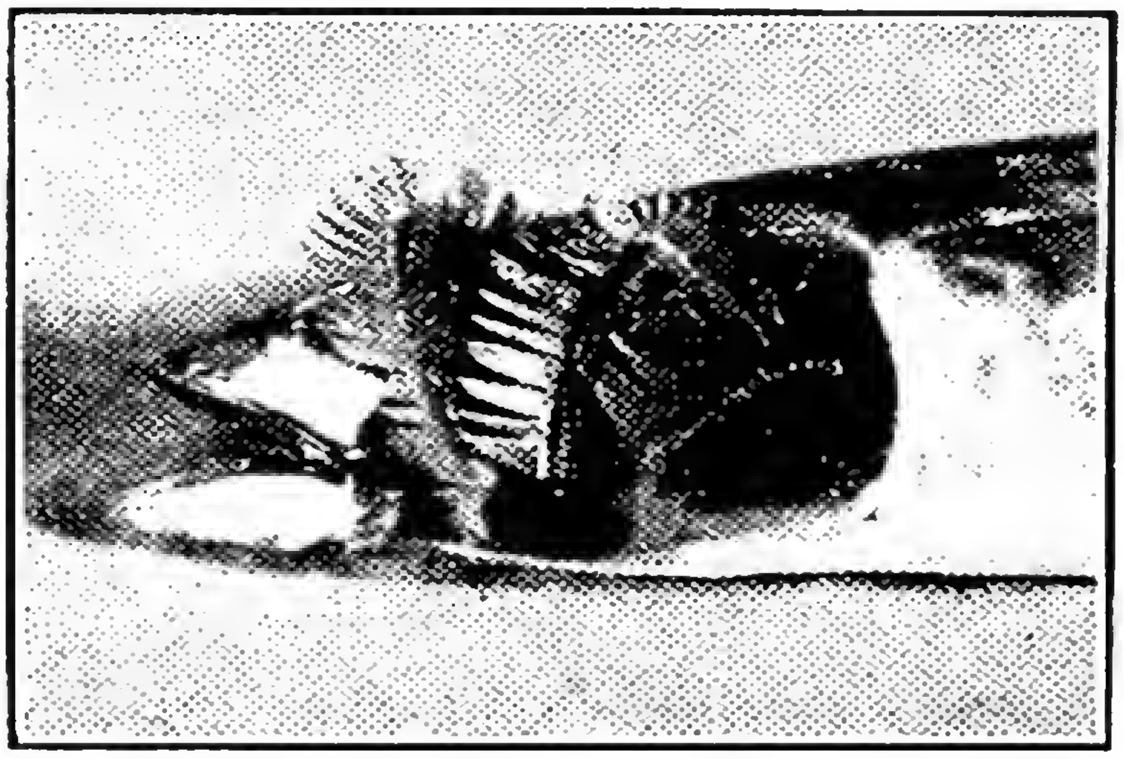


Fig. 76. The gills of a mackerel, dissected to show their structure. Note the feathered appearance. Are these any more efficient than those of the tadpole? Is the feathering any finer?

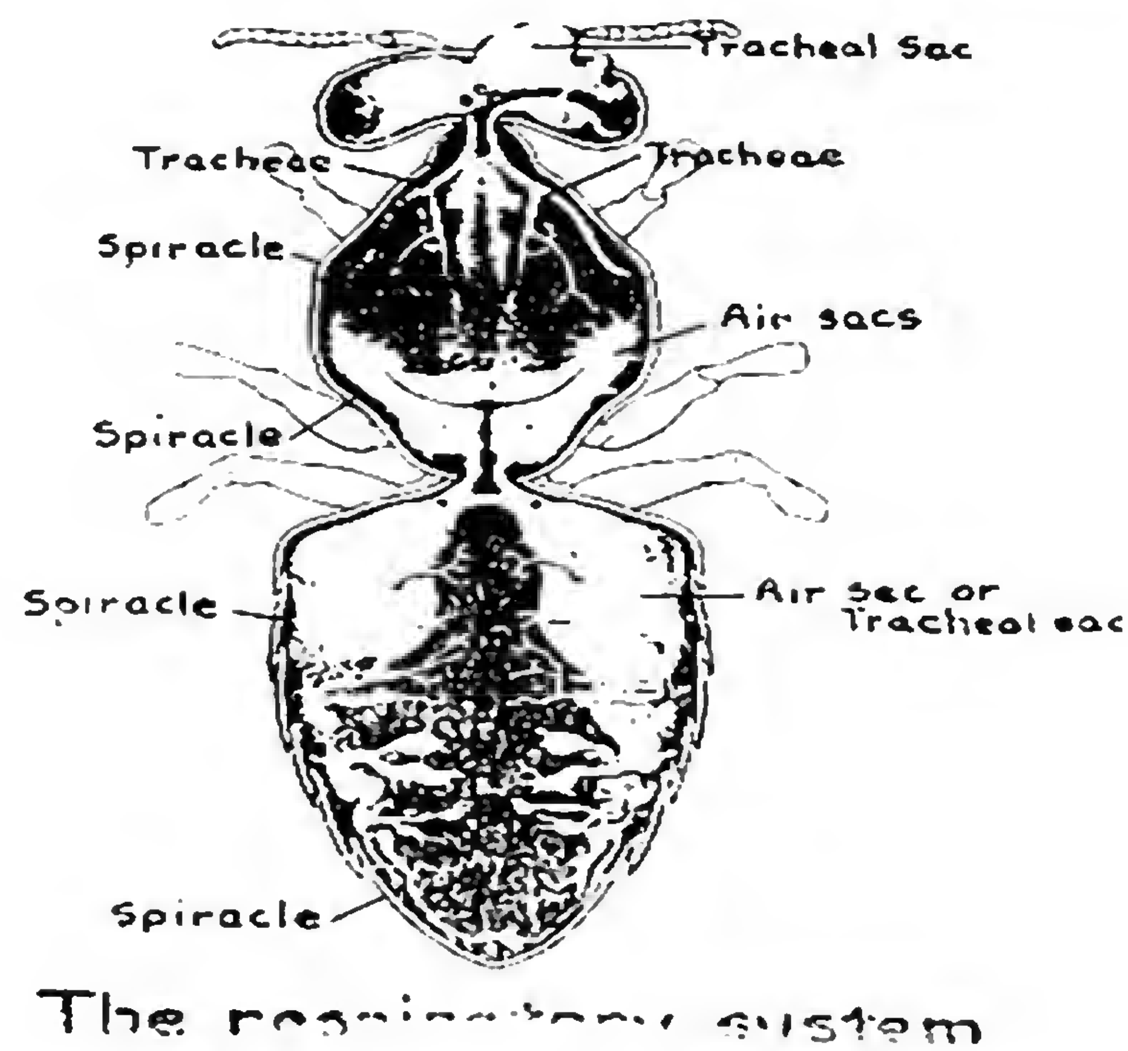
In the lower types of aquatic animals, such as the starfish, the gills may be simply openings in the body surface leading to small branched pouches or sacks. The water flows in and out irregularly, due to the movements of the organism. The body fluid in this type of animal also flows about inside the body cavity without any special motion.

In higher types, such as fish, water is taken in through the mouth and expelled through slits after it has passed over the gills. A motion of the fish's mouth causes this movement of the water, and may easily be seen. This action is not the same as swallowing, for the water never enters the digestive tract. Fish also have a definite circulatory system containing blood, with a heart to keep it moving.

Land animals breathe with some sort of lung structure. In insects there is a system of fine branching tubes which extend to all parts of the body. These tubes have many openings through which air makes its way into and out of them. They reach all parts of the body directly, and in addition, the insect has a fairly well-developed circulatory

system, including a heart. Insect sprays operate by filling the air with thousands of small drops of some light oil. These droplets get in the breathing tubes of the insects and block them up, and the insects smother to death before the droplets evaporate. A spray of fine powder or dust particles acts in the same way.

The higher land animals have true lungs. In the lungs, which contain a great many fine sacks, air is forced in and out by the breathing movements. Frogs, lizards, and some other animals breathe by moving their mouths and throats. Most of the higher animals move either the chest or the abdomen or both. In the lungs, the blood passes in very small blood vessels close to the surface. Oxygen is absorbed and carbon dioxide is given off. The blood is pumped by the heart to all parts of the body, where it gives up its oxygen to the cells and receives more carbon dioxide. Then it goes back to the lungs and exchanges the carbon dioxide for oxygen again. The blood also carries food from the digestive organs to the cells.

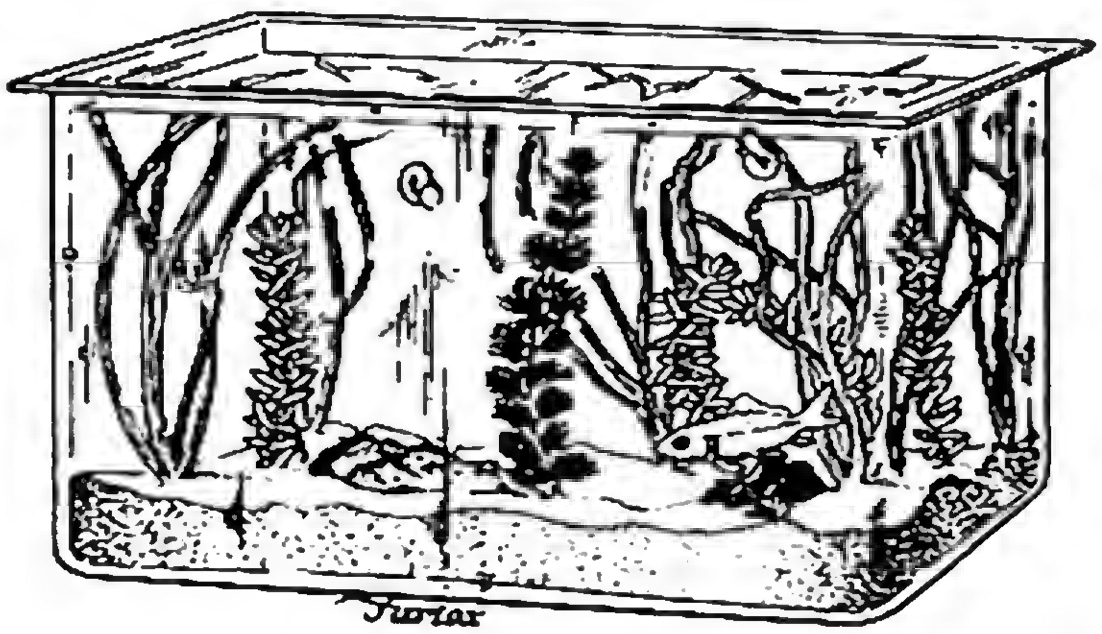


(Courtesy U. S. Department of Agriculture)

Fig. 77. The tubes of the insect's breathing system are called tracheae. The entrances where these tubes connect with the body surfaces are called spiracles. Can you guess what insect is shown here?

Experiment 15. Balanced Aquarium. Obtain a glass aquarium. Place about two inches of carefully washed pebbles on the bottom, and add one or two large stones. Then fill the aquarium with water. Visit a pond and secure some small water grasses that grow on the bottom. Fasten the roots of two or three of these among the pebbles. Leave until bubbles can be seen rising from the plants. Then add three or four small fish. These should not be over three inches long. Two or three tadpoles and one or two snails may be added

also. This arrangement is called a balanced aquarium because the plants supply food for the animals, and the animals' waste products provide food which the plants need in addition to what they can manufacture themselves. The photosynthesis of the plants will supply oxygen for the animals, and the respiration of the animals will supply carbon dioxide for the plants. If there are too many animals or too many plants, the water will become bad and have to be changed. If the balance is correct, however, it will not be necessary to change the water. The continued good health of the life in the aquarium is the best test of balance. It is important not to overcrowd the aquarium with too much life. The animals and plants described will be about all that can thrive in a two- or three-gallon aquarium.



(Courtesy General Biological Supply Co.)

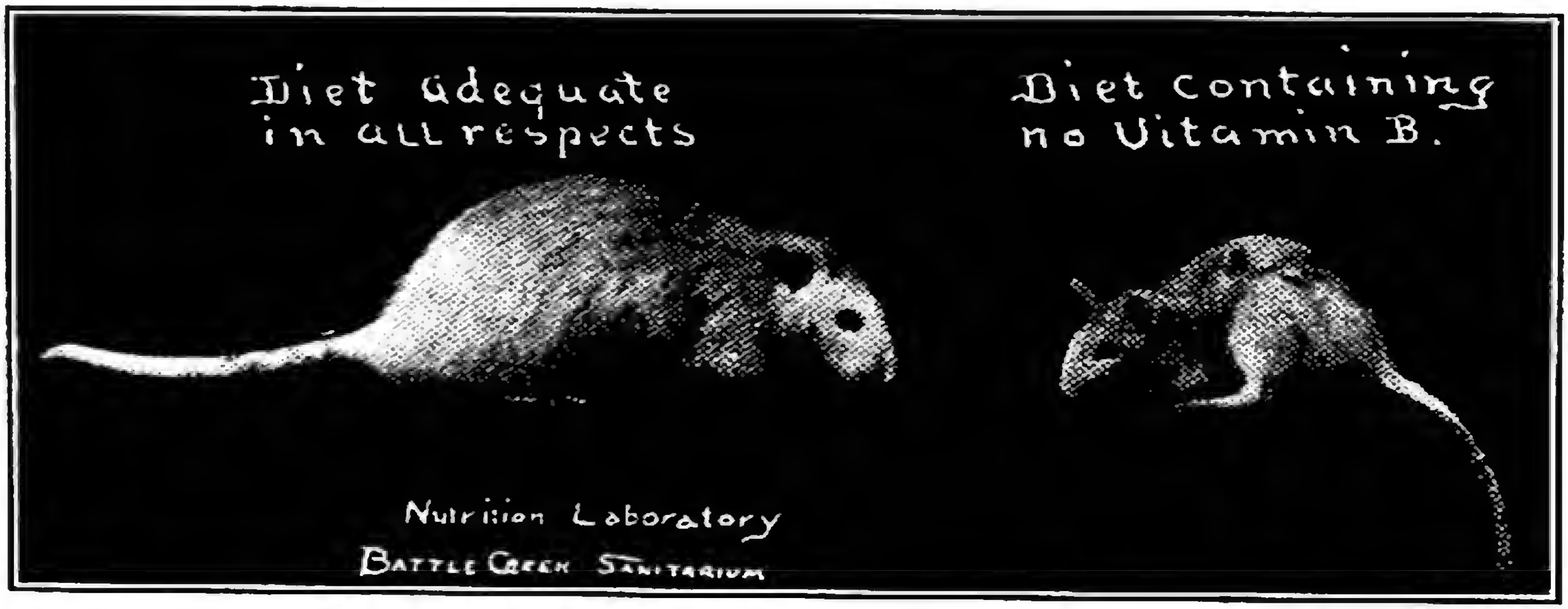
Fig. 78. A balanced aquarium. Compare the life shown here with that recommended in Experiment 15. What differences are there? Why the glass plate over the top of this aquarium?

Metabolism and Growth

There are many factors that influence the all-around individual well-being, or general metabolism, of animals and plants. The same factors speed up or slow down the growth of the young. If a young animal does not have enough food, or if it does not have the right variety of food, its growth will be slowed down. Food regulates the functioning of the body in several ways besides the mere supplying of energy and building material. Several minerals and a number of complicated chemicals, the vitamines, must be present in the diet or serious results will follow. One of these results may be the failure of normal growth.

Along with certain vitamines, light of a certain type is necessary for the normal growth and functioning of living things. This light must contain ultra-violet rays. These rays are present in sunlight. Too much exposure to them results in sunburn. They do not pass through glass as do the ordinary light rays. Quite recently, special glass and

fused quartz, as well as a special celluloid have been introduced which allow the ultra-violet rays to pass. Special electric lamps can also be had which give ultra-violet light in addition to the ordinary rays. It is believed that people who live and work in houses, always wear heavy dark clothes, and seldom go outdoors, receive too little ultra-violet light. More recently, many people have gone to the other extreme. A heavy coat of tan is not necessary as an



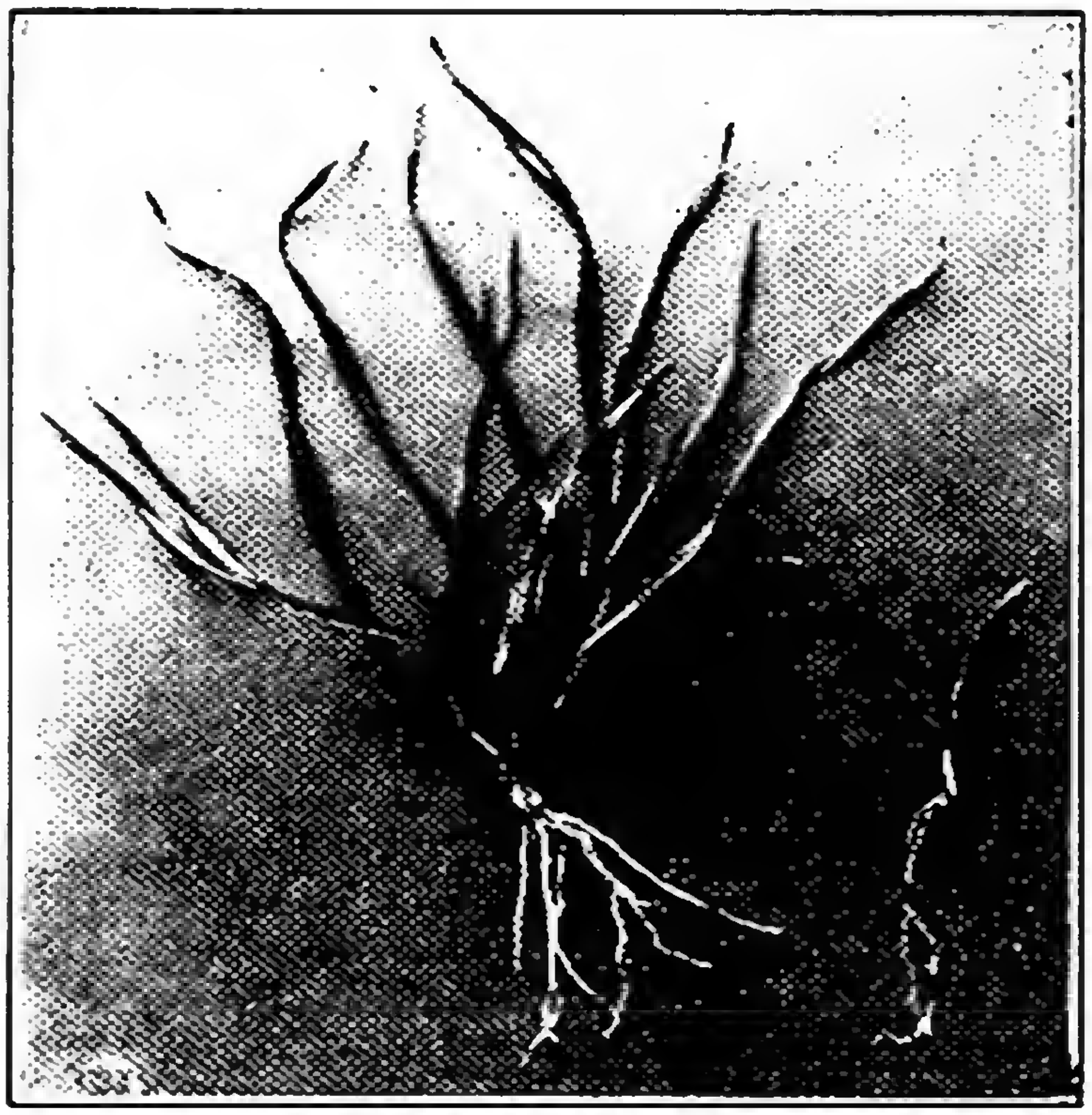
(Courtesy U. S. Department of Agriculture)

Fig. 79. These two rats have the same parents, are of the same age, and both have had plenty of food. But the food supplied to the scrawny one lacked an important chemical.

indicator of sufficient ultra-violet exposure, and there are some who think that too much of this exposure is bad, even though actual sunburn may not result. Plants need light even more than do animals, for without light the leaves are unable to build food materials.

All living things must have water. It is an essential part of protoplasm. It is the carrier of dissolved gases, minerals, and organic materials. It forms by far the major part of the weight of most living organisms. In plants it is also used along with carbon dioxide as one of the basic materials from which the leaf builds up foods. An under-supply of water prevents normal growth and leads to many bodily disorders in both animals and plants.

Life can exist only within a comparatively narrow temperature range. Growth is hindered by either too high or too low a temperature, and the range here is even less. At low temperatures plants and animals freeze. Even before they freeze, growth slows down or stops. Trees and other plants grow very little in the winter when the ground is covered with snow. In the spring they grow very rapidly again. At high temperatures growth again stops, and if these temperatures increase further or stay up very long at a time, the result is death.



(Courtesy U. S. Department of Agriculture)

Fig. 80. The wheat seedling on the left was grown under favorable conditions; the one on the right, under unfavorable conditions. Note the contrast. What unfavorable conditions may have affected the seedlings on the right?

Within its limiting conditions, however, life is remarkably persistent. The very stopping of growth by conditions not severe enough to cause death is an illustration of this fact, for by giving up this function the organism has more resources to devote to maintaining its life. So we see again the operation of the tendency that is perhaps the most characteristic feature of life, the tendency to keep the organism intact as an individual, and to remain alive.

Questions for Review, Discussion, and Study

Chapter V

1. What do you understand by a "complex" animal as opposed to a "simple" one? In what ways is a chicken more complex than a starfish?

2. Why is "sea-star" a better name for the starfish than "starfish" is?
3. Do human beings ever have any parasites living in or upon their bodies?
4. See if you can name five herbivorous animals. Five carnivorous animals. Five omnivorous animals.
5. Analyze your own movements in walking, and see if they follow the general principle of picking up some part of the body, advancing and "fastening" it, then advancing the body, and so on.
6. Would your general method of locomotion be much different *in principle* if you were crawling, with your hands tied behind your back, and your feet tied together?
7. Among all the animals, does man stand near the top in speed of locomotion, or near the bottom?
8. What animal has the most complicated way of getting, preparing, and eating, food?
9. What do gills do that lungs cannot? What do lungs do that gills cannot?
10. Compare arteries and veins as to the amounts of carbon dioxide in the blood flowing in them. Do the same for the oxygen in the blood.
11. Have you ever seen ultra-violet light? What color is it?
12. Can you think of any living thing, either plant or animal, which does not respond to any stimulus?
13. If you were forced to use one of the three words—walking, crawling, or swimming—which would you apply to the amœba's method of locomotion? Which would you apply to the paramecium's method?
14. Three new words are introduced in this chapter: coelenterates, echinoderms, and crustaceans. Give from memory examples of each.
15. Which are higher types of animals—sponges or coelenterates? Echinoderms or worms? Fishes or birds? Amphibians or reptiles?
16. Name the highest animal in our system of classification.

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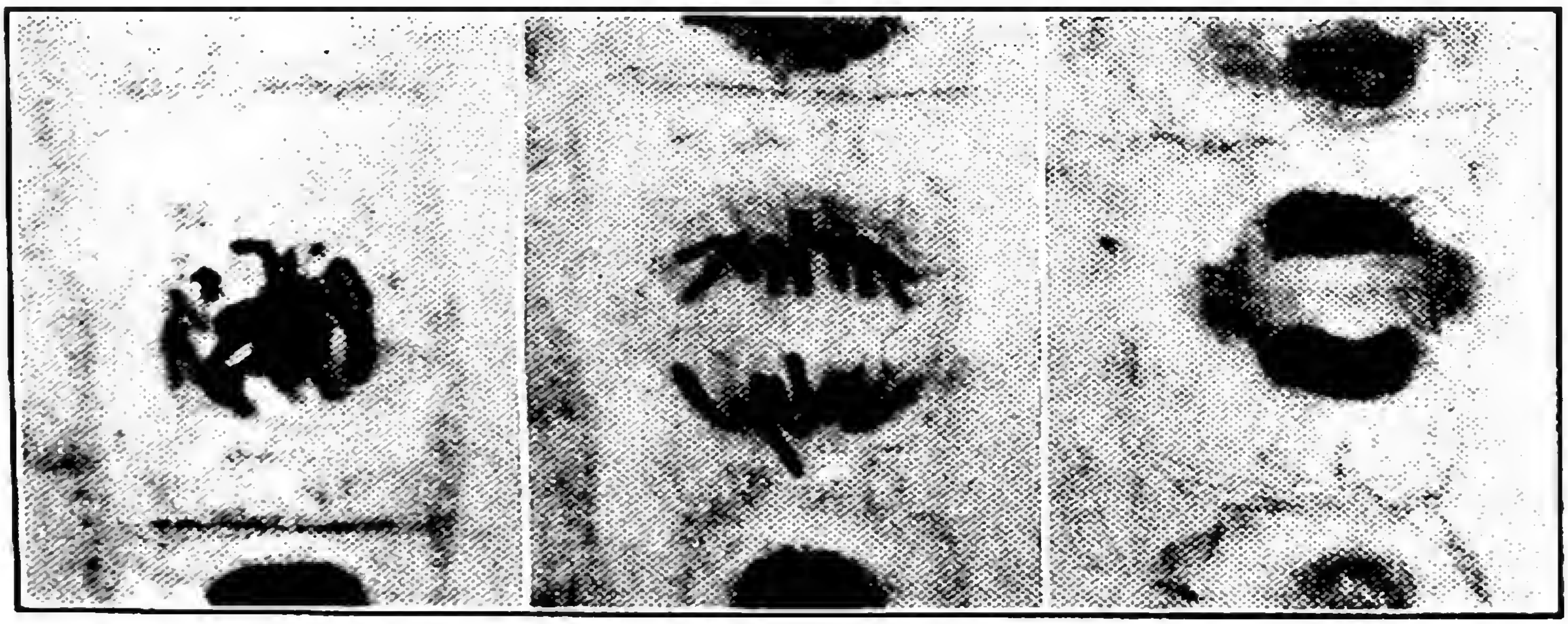
CHAPTER VI

PLANT GROWTH

Reproduction in Plants

Growth is one of the most important of life activities. If plants and animals did not grow they would be unable to reproduce themselves, and in a short time all life would vanish. Individuals grow and populations grow. Individuals have to die, but species do not. A species may stop increasing in number, or even become smaller; but it dies

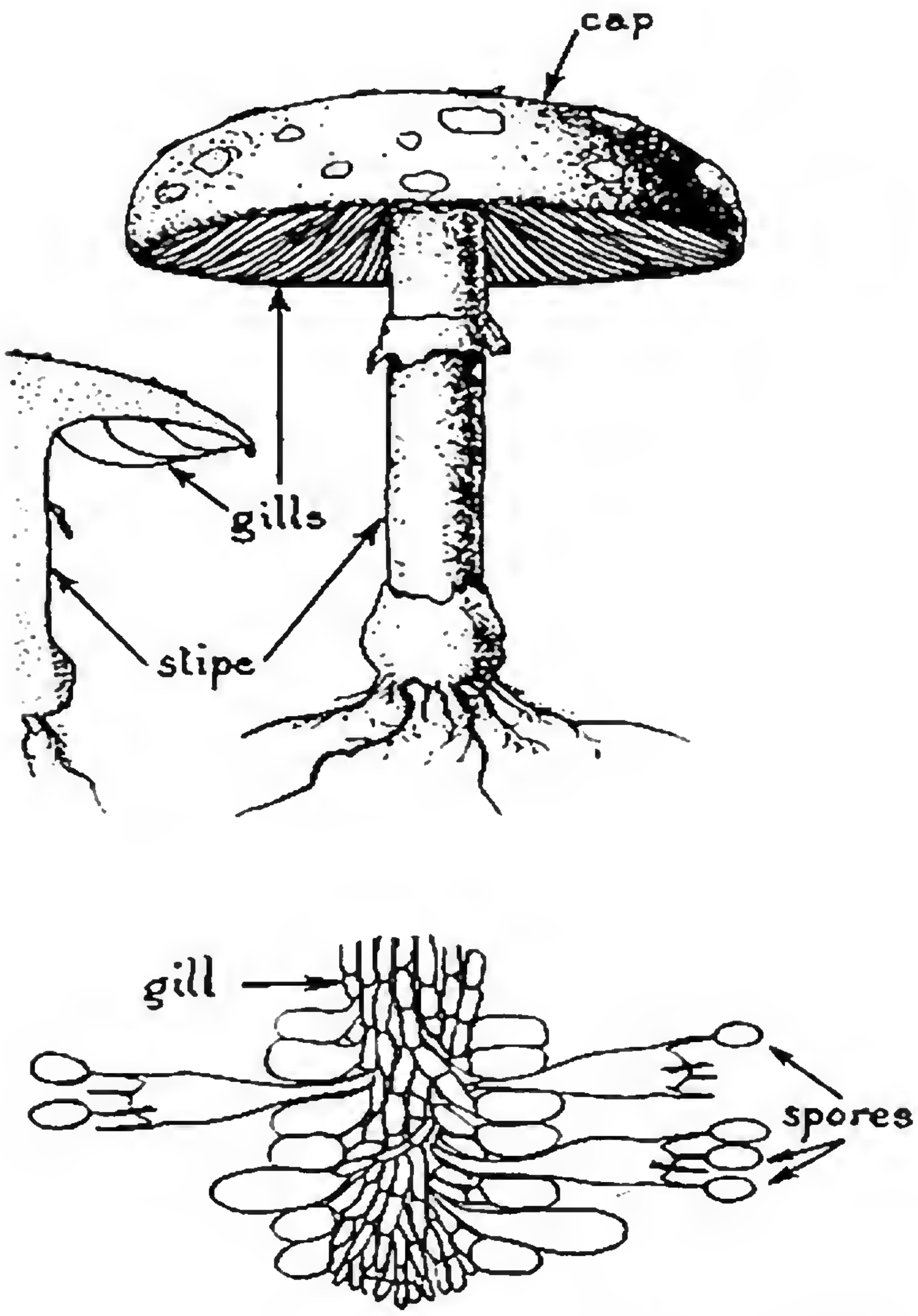


(Photo by New York Biological Supply Co.)

Figs. 81a, 81b, and 81c. Three stages in the process of cell division in the tip of an onion root. These photographs were taken through a powerful microscope. The first view shows the cell nucleus preparing to divide. The second view shows the nucleus in the act of dividing. In the third view the nucleus has split in two. Note the shadowy line separating the two new nuclei in the third view. The new cell walls will separate the new cells at this place.

only as the result of some important change in the basic environment, such as the coming in of an enemy stronger than it is. A species increases in number by the reproduction of its members.

The simplest form of reproduction is found in one-celled organisms. When such a plant or animal has grown to a certain size, the nucleus splits in two and half goes to each end of the cell. Then the cell body becomes smaller and smaller near the center, and finally it splits apart and there are two individuals. Cell-division in many-celled organisms goes on in somewhat the same way, except that at the end the two cells remain stuck together. Bacteria and a few algæ and fungi reproduce by simple cell-division.



(Courtesy A. E. Navez)

Fig. 82. This drawing of a mushroom shows in the upper part a complete view and one half of the cross-section (at the left) of the reproduction apparatus of a fungus. Notice the gills hanging at the under side of the cap. The lower part of the drawing shows a portion of one gill much enlarged. Spores are formed on the gills. Can you find in the drawing places where spores have already been discharged?

In some of the fungi and algae asexual, or non-sexual, spores are formed. The spore is a special reproductive cell. It is usually very small. A plant may produce millions of spores in a season. These spores are blown about by the wind and carried about by water. Most of them die. But a few of them find the right conditions for life, and grow into new plants which produce more spores. The common bread-mold and many other fungi reproduce by this method, and so do a number of species of algæ.

Some of the higher algæ and fungi reproduce by means of sexual cells. The plant produces two types of these cells, male and female, and these must unite to form the

germ-cell from which a new plant starts. In some plants both kinds of sexual cells are thrown off into the water or on the damp ground. In others only the male cell, or sperm, is thrown off, the female cell or egg-cell being kept in the plant. The sperm swims about until it comes in contact with an egg-cell or until it dies.

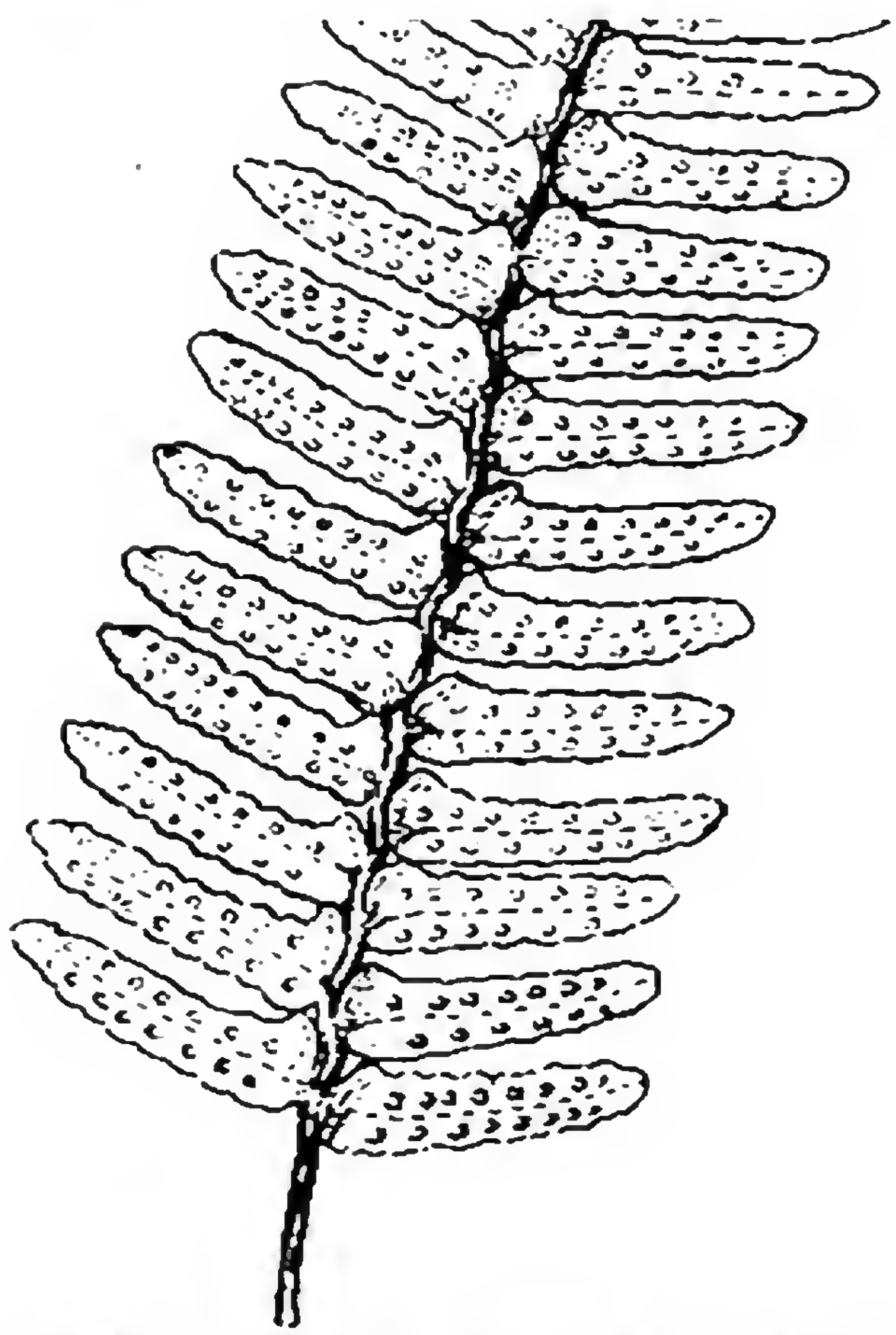
The germ-cell formed by the union of the two sexual cells may surround itself with a hard protective covering which enables it to dry up and withstand adverse conditions. But when it is moistened it comes to life again. One reason why all the lower plants must live in or near the water is that reproduction cannot take place without the possibility of the male cell's swimming to the location of the female cell.

Mosses and ferns reproduce by means of spores. In these plants, however, there are two different types of generations which follow each other in succession. One of these develops from an asexual spore, and at the maturity the plant produces sexual cells. These unite and grow into the second-generation plant, which produces asexual spores again. In the mosses, the generation developed from the asexual spore is the most important. The generation that develops from the union of the sexual cells often lives as a parasite upon it. With the ferns the case is almost the reverse. The generation produced from

(From student drawings, Department of Botany, Harvard University)

Fig. 83. The main, bushy part of the moss is the part we ordinarily notice. The slender branch with the cap at its end is a separate plant, growing upon the main one, and serving mainly to produce the spores from which a new plant like the main plant will grow.

the union of the sexual cells is the main plant, and the asexual spores develop into small organs growing upon it. The only function of this parasite generation is to take part in the production of the sex cells.



(From student drawings, Department of Botany, Harvard University.)

Fig. 84. The small round organs on the fern leaf produce spores. From one of these spores grows a small plant which few people ever see, but which is important because it in turn produces sex cells. Fertilization of the sex cells results in the growth of another fern plant like the one shown.

The distinguishing character of the so-called "higher plants" is that they reproduce by means of seeds. This method of reproduction will be considereed in detail in later paragraphs. The seed-bearing plants do not have to live near open water to enable the sperm to swim to the egg-cell, and these plants are therefore able to live in regions in which the only water available is under the ground.

There are two classes of seed-plants. In one of these the seeds are carried in cones, and the plant is called a conifer. There are comparatively few species of this type, but these include some of the most important trees. The pines, firs, spruces, the redwood, the bigtree, and several other evergreens belong to this group. Some of the bigtrees are the oldest and largest living organisms on the Earth. A few of these are estimated to have been large substantial trees at the beginning of the Christian era.

The most important and widespread of the seed-bearing plants are those which produce flowers. There are probably as many species of flowering plants as there are of all others put together.

Growth and Reproduction in Flowering Plants

Flowering plants grow from seeds. The seed contains the germ formed by the union of a male cell and a female cell, and in addition a quantity of food material that may vary from practically none to a great deal. As a rule the seed has a strong outer covering of some sort. When it is put in damp ground of the right sort, the germ begins to grow. It sends a small root downward into the ground and a small shoot upward into the air and sunshine. This process is called germination.

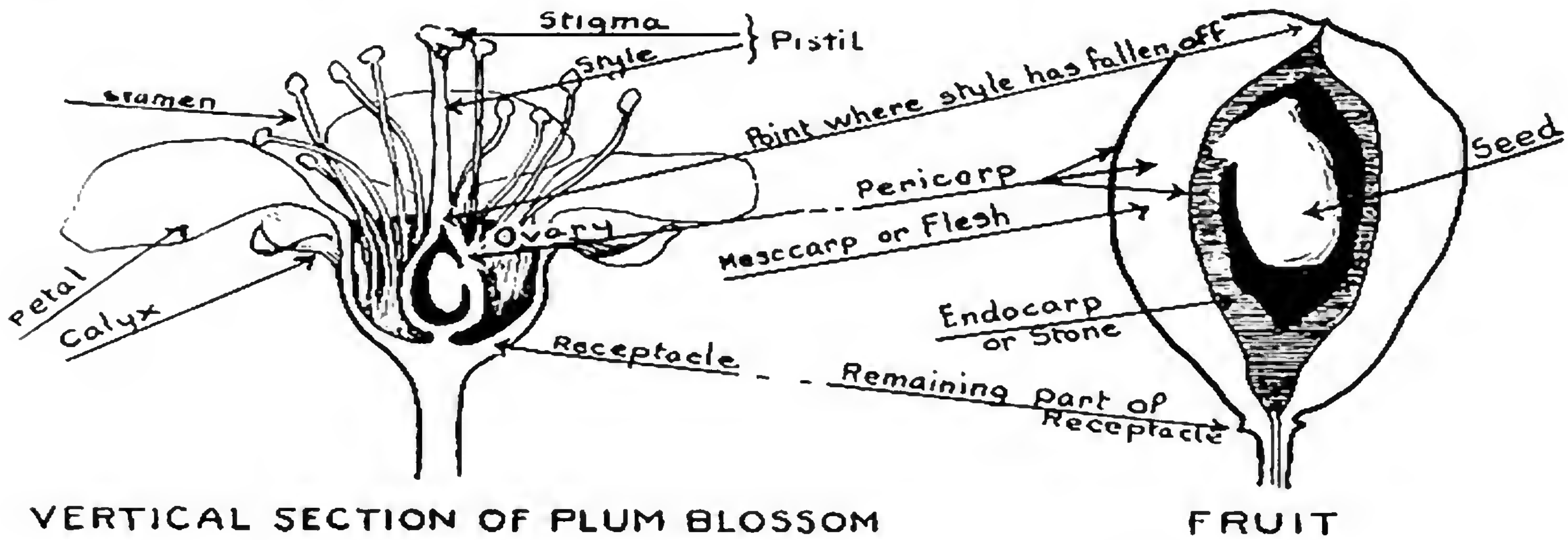
At first the plant lives on the food stored in the seed. By the time this is gone, the root should have developed root hairs and the shoot leaves, so that the plant is able to maintain itself. If the root fails to find water or the right minerals, or if the leaf is unable to get to the light, the plant will die as soon as the food materials stored in the seed are used up.

Plants continue to grow as long as they live. The stems send out branches and twigs which support the leaves and flowers. The roots also branch and continue to grow. A fairly considerable portion of the food manufactured by the plant is used in its growth. The growth in length of branches and roots takes place almost entirely at the tips. The central parts of the plant grow thicker but no longer.

Experiment 16. Bring to school beans, corn, wheat, and oats. Fill a box with rich loam. Plant a row of seeds of each kind, the first on top of the earth, the next a little lower, and so on, the last being about five inches below the surface. Keep the soil damp, not wet, for several days. Keep it in the sunlight as much as possible. Note the best depth for planting different seeds. See which ones become moldy or decay. At the end of ten or twelve days, dig up all the seedlings. Note just what happens when different seeds germinate. In some the original seed stays in the ground, and in others it is lifted into the air.

At the start the young plant develops only roots, stems, and leaves. After a time, however, flowers appear. The plant is then mature. From the flowers come new seeds,

which are scattered and produce new plants when they germinate. Some plants live only to produce a single set of flowers and seeds, and then die. If this process takes place in a year the plant is called an annual. If it takes two years the plant is called a biennial. Other plants grow for several years before the first flowers appear. After the seeds are scattered and the flowers die, the plant as a whole continues to live. The following year new flowers and new seeds are produced, and this process may go on for years and even centuries. Plants of this type are called perennials.



(Courtesy U. S. Department of Agriculture)

Fig. 85. The plum blossom is a typical flower. Note the various parts. In the diagram of the plum fruit, note which parts came from the flower parts. Some of the words in the diagram have not been explained in the text. Which ones are they? Are the meanings of these words clear?

Flowers and their Functions

Flowers are concerned only with the function of reproduction. They do not appear on a plant until it reaches maturity. There are at least two basic parts of every flower: the stamen or male part, and the pistil or female part. The stamens (there are usually several) produce the pollen grains which carry the male cells, and the pistil produces the female cell or egg-cell. The pistil and stamens may be together in the same flower, or they may be separated, as in corn, where the tassel contains the stamens and

the young ear contains the pistils. Most flowers also have a green structure, at the base, called the calyx, and a set of brightly colored petals.

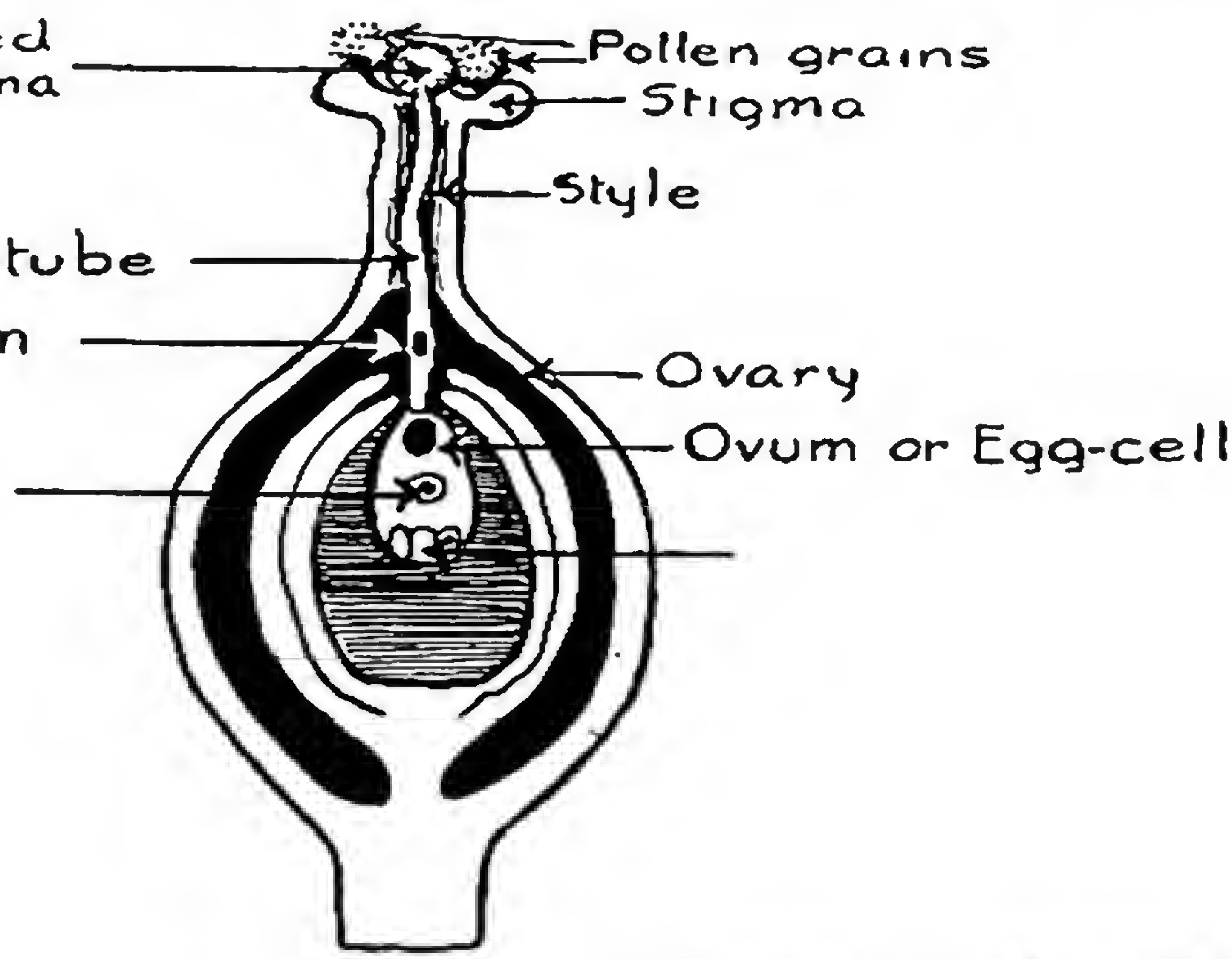
Pollen must be carried from the stamen to the pistil in order for the seed to be formed. If fertilization takes place by the pollen's being carried from the stamen to the pistil of a flower of the same plant, the plant is said to be self-fertilized. If the pollen is carried to the pistil of a flower on another plant, of the same species, the process is called cross-fertilization. More species are cross-fertilized than are self-fertilized. A number may be either self-fertilized or cross-fertilized.

The pollen is carried from stamen to pistil in several ways. It may simply drop by gravity. It may be blown by the wind. In a few exceptional plants that live by the water's edge, it may be carried by the current. Birds sometimes carry pollen long distances. The most important carriers, however, are insects. These insects are attracted by the bright colors of the petals and by the pleasant odor of the honey or nectar which the petals contain. They alight to gather the nectar, and in so doing they may brush against the stamens and carry away grains of pollen. Alighting on other plants they may brush against the sticky tips of the pistils, leaving the pollen grains there to bring about fertilization.

The Seed

When a pollen grain reaches the pistil of a plant of the same species, it germinates somewhat as does a seed in warm moist ground. It sends out a long slender thread which goes down the pistil to the egg-cell at the bottom. When it gets there the nucleus of the sperm descends into the egg and joins with the nucleus of the egg-cell. The egg-cell is then said to be fertilized, and it starts at once to grow into a seed. It may be contained in a fruit, a hard nut-shell, a husk, or a pod.

The seed consists of the germ or embryo—a body consisting of several cells formed by division of the egg-cell—and a greater or less amount of stored food. The stored food of seeds forms one of the most important sources of human and animal food supply. Wheat, corn, rye, oats,



(Courtesy U. S. Department of Agriculture)

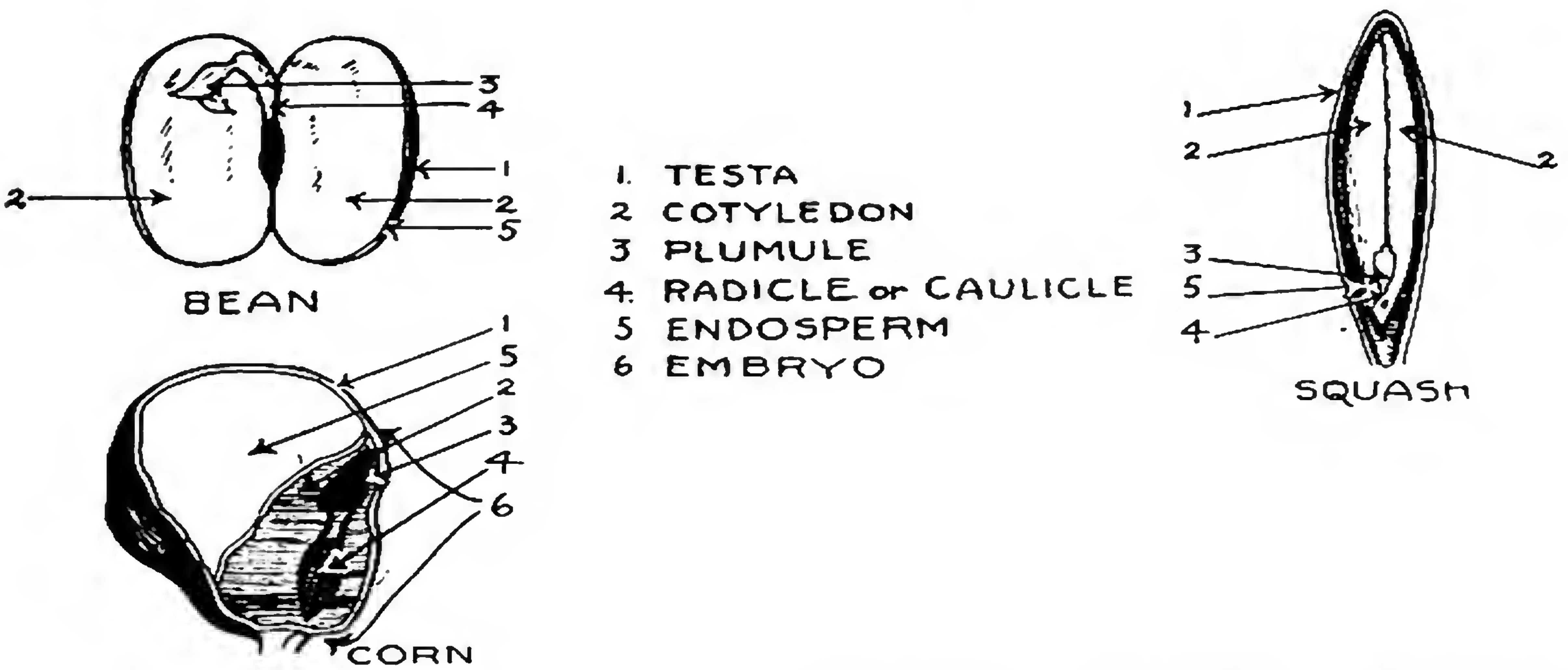
Fig 86. This cross-section diagram shows the path of the pollen tube from the germinated pollen grain down to the egg-cell in the ovary. Can you see what part of the flower in Fig. 85 is represented here?

and rice are among the more important of the seeds used for food by man.

As the seed is formed the flower dies. In some plants, such as the pea, the flower has died and been discarded by the time the seed is fully developed. When the seed is fully developed, it usually enters a resting stage. It stops growing until germination finally takes place.

The seeds, once formed, must be scattered. This comes about in many ways. In a few plants, such as the pea, the pod curls up as it dries out, and shoots the seeds to a distance. In others, gravity and the wind play the main parts. A few seeds are provided with special wings or parachutes or sails to enable the wind to carry them. One

of the most important of these is the cotton plant, which has a greatly overgrown system of fibrous sails that provide mankind with much of his clothing. Some seeds float away on streams and lakes and finally come to rest. Many seeds are carried about by birds and animals, which like to eat



(Courtesy U. S. Department of Agriculture)

Fig. 87. The seeds of three different plants are here shown opened up. In each view, the Figure 2 points to a cotyledon. Plants whose seeds contain two of these are called dicots. Can you figure out the meaning of the word "monocot?" Which of the three seeds shown are from monocots?

the fruits or berries that enclose them. In addition, some seeds are encased in burrs which become attached to birds or animals and so are transported from place to place.

After the seed comes to rest in the ground it may germinate at once or it may require several months or even years before germination starts. Conditions must be just right or germination will not take place. The seed must have water, air, and the proper temperature. Water is needed to replace that of the nearly dry protoplasm and the dry food material. If the ground contains too much water, however, the air will be kept out. The seed needs air in order to get oxygen to resume the process of respiration. Finally, if the temperature is either too high or too low, the

proper stimulation will not be afforded and the seed will not start to grow. Even when all these conditions are right, it is necessary in some seeds for the outer coverings to decay or fall apart before growth can start. Germination marks the ending of the embryo stage in plants, and the beginning of life as an independent organism.

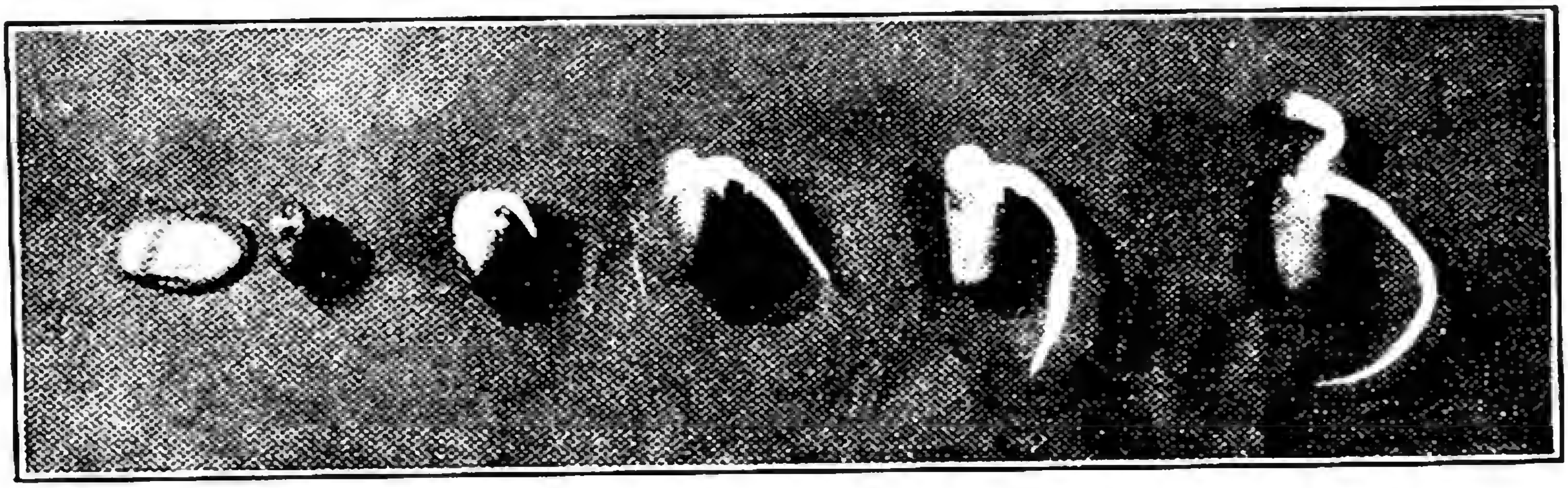


Fig. 88. Germination of the Broad Windsor bean seed. The first two seeds have been in the ground one day, the next seed, two days, the next, three, and so on. Can you distinguish the root from the shoot in the sixth view? In the others?

Experiment 17. Select a number of kernels of corn from the same cob. Prepare four germinators as follows: for each germinator fill a saucer about half full of fine sand. Over this lay a piece of wet cloth. Put about half a dozen kernels on the cloth, and cover with two or three more layers of wet cloth. Put about a tablespoonful of water under the lower cloth. The water should dampen the sand but should not form pools of water touching the seeds. Set one saucer in the sunlight. Set another in a dark closet. Set the third in the sunlight, but take it home each night and put it in the coldest part of a refrigerator. Set the fourth in the sunlight, but keep it filled with water to the brim. The other three should be kept damp at all times but never too full of water. At the end of two weeks open and examine the seeds.

Most plants produce many more seeds than are ever likely to grow. Most of these seeds fall on unfavorable spots. Though the seed is protected so as to be able to live a long time in the dormant or resting stage, it must eventually either germinate or die. If the protoplasm of the germ becomes completely dry, or if the seed falls in

ground so wet that oxygen is kept from it for a long enough time, it will perish.

Seeds differ in their vitality and in the characters they transmit. Seeds from good plants produce good plants, and seeds from poor plants produce poor plants. In the days before scientific farming, farmers often used the poorest ears of corn for seeds, and then wondered why their crops became poorer year by year. Today they save the best ears for seed, and as a result their crops become better each year. Ears are tested for vitality before they are used.

Experiment 18. Select a half-dozen kernels from each of five ears of corn. Put the kernels from the first ear on top of three thicknesses of damp cloth. Put another damp cloth of three layers over them. Roll the cloth up and tie it. Repeat the process for each of the other ears. Put these bundles in a fairly warm place, and dampen them every day for three or four days, being careful not to soak them. At the end of this time they should be opened. The seeds or kernels will have germinated, and it should now be possible to tell which ears are most likely to produce strong, healthy plants. The same process may be used to test beans, wheat, and other grains.

Bi-sexual Plants

In most plants the male and female parts are found together in the same organism. In a few, however, such as the fig, date palm, asparagus, cottonwood, and willow, the male parts or stamens develop in one individual and the female parts or pistils in another. Such plants must necessarily be cross-fertilized. In contrast to the higher animals, which are all bi-sexual, these plants are held to be of a lower type than those in which each flower has both pistil and stamens.

Questions for Review, Discussion, and Study

Chapter VI

1. The text implies that a plant species may have enemies. Can you think of a plant which might destroy another species if care were not taken to prevent it?

2. Can you see any connection between the complexity of a plant and the complexity of its methods of reproduction? Consider algæ, mushrooms, and flowering plants.

3. Review the types of plants which reproduce by means of spores.

4. Have you ever seen mosses? Where?

5. Think of the plants you have seen growing in very damp places. Were they mostly lower forms, like ferns, pond scum, and toadstools, or higher forms like daisies. oak trees, and corn?

6. From what you have read, do you think there are any lower plants which have seeds?

7. When speaking of a full-grown flowering plant, what does the "shoot" include?

8. Give an example of an "annual" plant. Of a perennial.

9. Have you ever seen pollen? What color was it?

10. What do you suppose would result if the pollen from one species of plant were to fertilize the ova of another species?

11. When so many seeds are produced by a single plant, why doesn't the Earth soon become crowded with the many new plants growing from the seeds?

12. Have you seen seeds with sails or cottony puffs to assist in distribution by the wind? How about thistle seeds? Maple seeds?

13. In the experiment on seed germination, you were told to be sure not to have pools of water touching the seeds. Why is this requirement necessary?

14. If you know that bread mold is a low form of fungus, can you tell how it reproduces?

15. What peculiar method does the pea use in distributing its ripe seeds?

16. What must a pollen grain fall upon before it will germinate?

17. Is there any such thing as an unfertilized pea seed?

18. How might you be able to tell the age of a tree after it has been felled?

19. Can you name some plants whose seeds are encased in very hard coverings?

20. Could some species of plants be both self-fertilized and cross-fertilized? How about corn?

CHAPTER VII

ANIMAL GROWTH

Reproduction in the Lower Animals

The lowest animals, like the lowest plants, reproduce by simple cell-division. One-celled organisms like the amœba and paramecium, when they have grown to a certain size, simply split into two individuals.

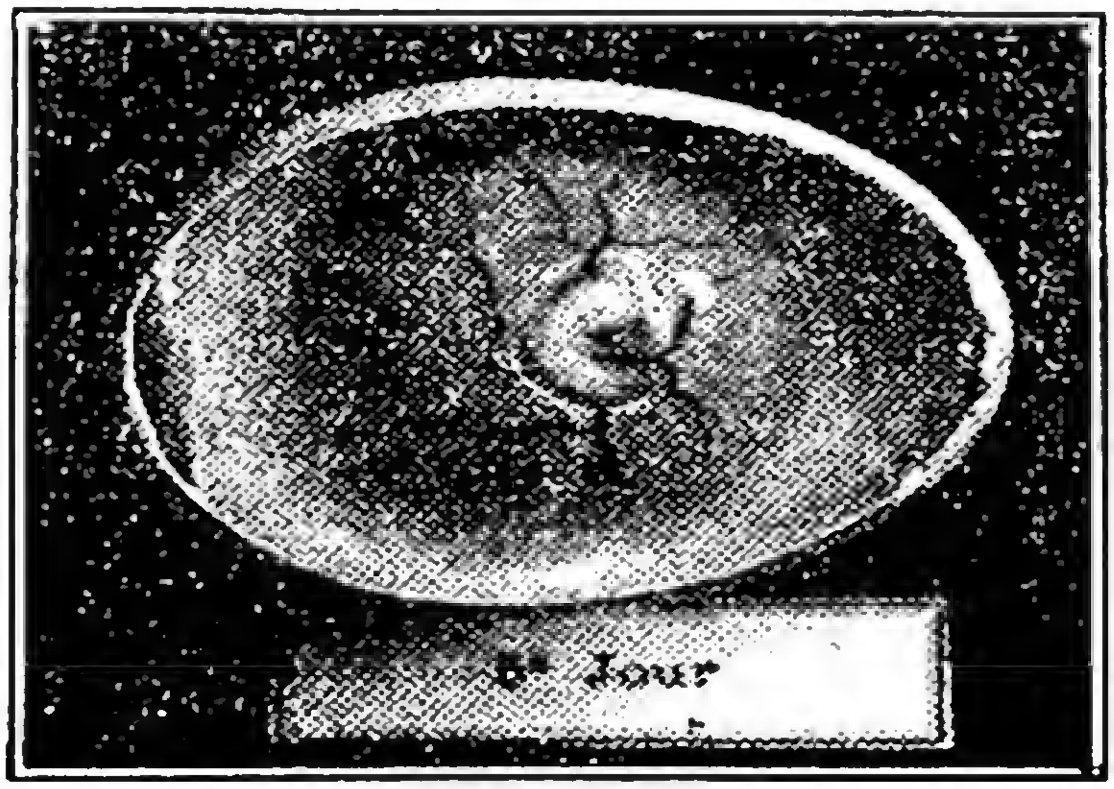
Animals a little higher in the scale of life, such as the sea anemones, reproduce by budding. A part of the body grows out into a small bud on the side of the parent, and this breaks off and grows into a new animal. The same organism may produce many buds before it dies.

Animals do not as a rule reproduce by means of spores as do many plants. A few species of one-celled animals, however, instead of dividing into two individuals, break up into a great number of smaller ones. These are called spores, though they are different in many ways from plant spores, particularly in that the organism that produces them contributes much of its living protoplasm to them, and dies when they are liberated.

Many of the lower animals and all the higher ones reproduce by means of sexual cells. In worms and snails, and in a number of the other lower forms, both the male and female cells are produced in the same animal. In insects, fish, and all higher animals, each individual produces only one type of reproductive cell, and the species is divided into males and females. This condition is the reverse of that found among plants, in which each individual of nearly all the higher species produces both egg-cells and sperm-cells.

In nearly all aquatic or water-dwelling animals, the eggs of the female are laid in the water before fertilization. The male then sends the sperm cells into the water close by, and they swim to the egg-cells and fertilize them. This method

of reproduction is very inefficient, and to make up for the inefficiency, the animal must produce hundreds or thousands of eggs or sperm at a time. Many of the eggs are never fertilized. Of those that are, most are eaten by animals of other species or even of the same species before they have grown large enough to care for themselves. Many die from lack of food. But a few usually manage to survive and propagate others, so that the species does not vanish.



(Courtesy American Museum of Natural History, New York)

Fig. 89. This model shows a hen's egg opened up on the fifth day of incubation. The chick embryo is seen in the center, with blood vessels radiating from it, encircling the yolk of the egg. The yolk provides food for the growing embryo during the period of incubation.

Reproduction in Land Animals

In the land animals, fertilization usually takes place before the eggs are laid. The eggs of some reptiles have soft shells as do those of fish and lower marine forms. Those of other reptiles have hard shells as do the eggs of birds. In such eggs, there is a large amount of stored food material. Fertilization must take place before the hard shell has formed. The germ develops into the embryo within the shell, living upon the food stored there. Finally it breaks out, or hatches. This point marks the end of its life as an embryo and the beginning of its life as an independent organism, just as does germination in seed-plants. The egg resembles the seed in its essential functioning. Both contain the germ or embryo. In both, fertilization must take place before the hard outer structure can be formed. Both contain stored food material, which is eaten by other animals and by man for food. Germination (when the young plant breaks from the seed) and

hatching (when the young animal breaks from the egg) both mark the beginning of the independent life of the organism and the end of its life as an embryo.

The reptiles are cold blooded animals, having the same temperature as the air or water about them. They lay their eggs in the sand or mud or humus and leave them to hatch by themselves. The birds are warm blooded, maintaining their bodies at a constant temperature which is usually much higher than that of their surroundings. Birds therefore lay their eggs in nests and sit upon them to keep them at body temperature until they hatch.

In mammals, as in birds and reptiles, there are male and female individuals in each species. Mammals are so named because the females have mammary glands, which produce milk for the young during the early stages of infancy. The milk of some mammals is used by man for food. The species most widely used for this purpose is the cow, but in some countries the goat is the commoner source. Goat's milk cheese is a staple food in some parts of the world, and is a delicacy enjoyed by many in all parts.

Mammals are warm-blooded animals; a small change in body-temperature results in disorders of bodily functions and not a very great change is necessary to cause death.

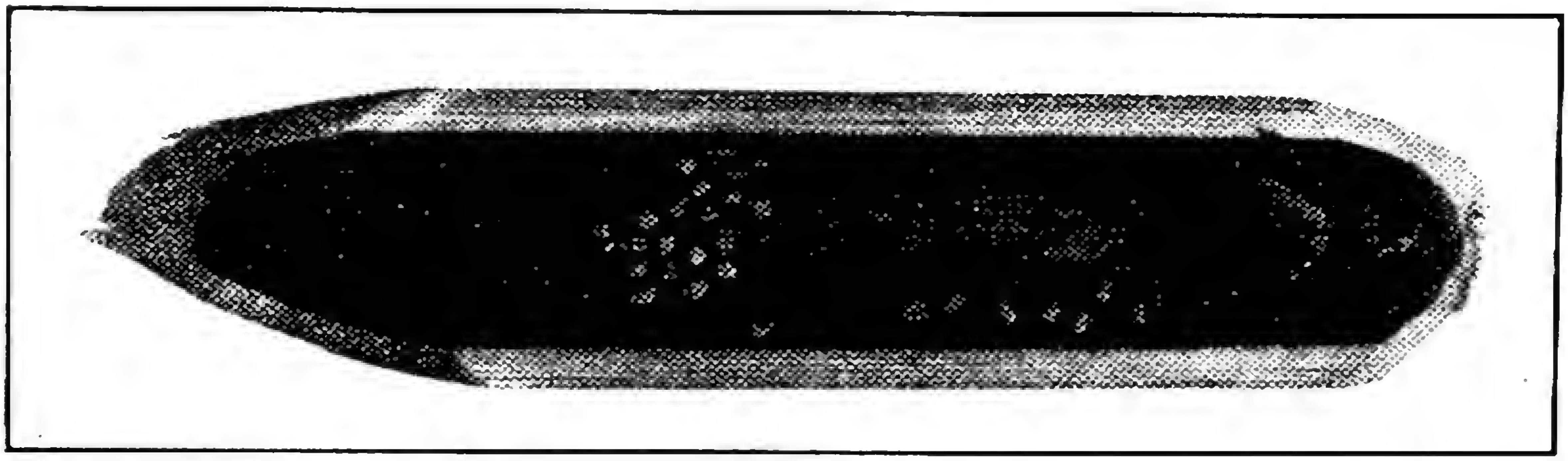
The eggs of mammals contain no stored food materials. Accordingly, the embryo must be supplied with nourishment from the very beginning of growth. Birth in mammals represents the end of life as an embryo and the beginning of independent life, just as does hatching in the case of birds and reptiles, and germination in the case of seed-bearing plants.

Metamorphosis

We have used the term "metamorphic" in connection with certain rocks that have been formed from other rocks. The metamorphosis in the case of rocks is the change from one type, such as shale or limestone, to another, such as slate or marble. We have observed far-reaching changes in

the mode of life of plants and animals, such as germination, hatching, and birth. Any such change may be called a metamorphosis.

A metamorphosis occurs in the life-history of practically every species of land animal, and in many species of aquatic animals. The same may be said of seed-bearing plants, but with some reservations. It is of interest to note in this connection that the seed-bearing plants, which undergo the metamorphosis of germination, nearly all live on the land. Most plants which reproduce by means of spores are, as we have previously noted, not fully adapted to life on the land, but require a damp medium to enable the sperm to reach the egg-cell. The metamorphosis in



(Courtesy American Museum of Natural History, New York)

Fig. 90. Note the jelly-like mass surrounding each egg, and the size of the eggs as compared to the size of the adult frog in the picture. The particular species shown here has unusually large eggs for the size of the frog. In most species the eggs are relatively much smaller.

animals often represents, essentially, a change from an aquatic mode of life to a life on the land. The embryo in the egg is living in a liquid. It obtains its oxygen from this liquid, and not directly from the air. Oxygen seeps through the tiny pores of egg-shells. If an egg is varnished or shellacked or painted, the embryo will die and the egg will never hatch.

Life History of the Frog

One of the most interesting groups of animals is the one that includes the frogs, toads, newts, and salamanders. These are called amphibians, from a Greek word meaning "double life." The amphibians represent a group midway between the aquatic animals and the land animals. They begin life as true water-dwellers, and finish it as true land-dwellers. They are cold-blooded animals, as are the fish and reptiles. They undergo a very remarkable metamorphosis at the time they emerge from the water and begin to live upon the land. The frog is a well known representative of this group.

(Photo by Boston Museum of Natural History)

Fig. 91. Six stages in the change from tadpole to frog. Does the tadpole grow much larger while changing into a frog? Notice the change in prominence of the eyes. Why are no gills shown?

The female frog lays her eggs in the water. The eggs each consist of a single egg-cell surrounded by a jelly-like covering. Fertilization occurs after the eggs have been laid, as is the case with fish. The male frog deposits sperm-cells in the water close to the egg-cells, and these sperm-cells swim to the egg-cells and fertilize them. A single frog may produce thousands of egg-cells or sperm-cells during a season.

A few days after fertilization has taken place, the eggs hatch. Hatching in this case, as in the case of fish, does not represent any very important change or metamorphosis. It marks the end of life as an embryo, and the beginning of independent existence, it is true, but the change is not very great. This change does not come at the same time

as the change from aquatic life to land life, as is the case with reptiles, birds, and mammals. The young tadpoles or polliwogs, as they are sometimes called, soon push their way out of the jelly-like covering. They look like small fish with large heads and small bodies and tails. Sometimes they attach themselves to the leaves of aquatic plants by means of their sucker mouths. Soon, however, they begin to swim about. They feed on small algæ and other green water plants.

Tadpoles have no fins. They swim about by swishing their long flat tails from side to side. They breathe through gills on the sides of their bodies. After a few days in the water they begin to develop the features of land animals. A covering grows over the gills. The tadpole takes in water through the nose. This passes back over the gills and out again through a small opening in the side of the body. A network of small blood-vessels in the gills absorbs the oxygen dissolved in the water. Lungs begin to develop, but these are not used at first. A pair of tiny buds appears about halfway between the nose and the tip of the tail. These buds gradually grow into the frog's hind legs.

The tadpole has many enemies. Fish and other aquatic animals eat tadpoles whenever they are able to catch them. As a consequence, most of the tadpoles that hatch from a set of eggs are eaten before they ever grow into frogs. But let us see how development proceeds in those tadpoles who do grow up.

After the hind legs of the tadpole appear, the growth of the tail slows down and finally stops. After a time front legs appear. The body continues to grow, and the lungs develop further. Finally the animal leaves the water. The gill opening closes up, and the lungs begin to operate. In a few days the tail is absorbed into the body, and the animal is now a frog—an animal capable of living on land as well as in the water. While the tail is being absorbed, the tadpole or frog does not eat.

We have seen that the metamorphosis or change is gradual. Toad tadpoles develop into toads in a month or two, while a bullfrog stays in the tadpole stage for two years. The gill hole does not close all at once. The tadpole does much of his breathing directly through the skin, and so does the frog. The fine blood-vessels come very close to the surface, and oxygen is absorbed directly from the water or the air. The frog has no ribs, so he uses his large mouth to force air into and out of his lungs. He does this by moving the skin under his lower jaw rapidly up and down.

The adult frog is lighter in color than is the tadpole. He moves on the land by a series of hops or jumps. The frog always stays near the water, but some animals of the same type, like the toad, never go back to the water after leaving it for the land, except to lay eggs. The hind legs of the frog are long and powerful, while his forelegs are short. In the water he swims by kicking the webbed feet of his hind legs back together and then drawing them forward more slowly and repeating the process.

Frogs are carnivorous. They eat insects, snails, and worms. This is another change in mode of life, for we have seen that the tadpole is herbivorous, living on vegetable matter.

In the fall the frog becomes slow and sluggish in his movements as the weather gets colder. Finally he digs deep into the mud on the bottom of some pond and stays there. Breathing stops entirely, and all the respiration that takes place is done by the skin. Heart action is very faint. In this condition the frog is said to be hibernating. Many other animals hibernate in the winter, among them the bear.

In the spring the hibernation comes to a close and the frog digs his way out again. He is very thin, having eaten nothing all winter. As soon as he has eaten he begins to croak. The frog's croak is his mating call. Eggs are laid in the spring. A female bullfrog may lay as many as

15,000 eggs in a season, but the females of other species seldom lay more than 1,000 each year.

Experiment 19. Visit a small pond and secure specimens of toad's eggs and tadpoles. Bring these to school and put them in the aquarium. Watch their development carefully for several days. Notice when the eggs hatch, when the hind legs appear and when the forelegs are first to be seen. Toad tadpoles are better for purposes of observation than are the tadpoles of frogs, because they develop much faster. If the tadpoles are small, it may be necessary to remove the fish from the aquarium before they are put in.

(Courtesy U. S. Department of Agriculture)

Fig. 92. Four stages in the life of the cabbage butterfly. At **a** is shown the adult butterfly. At **b** are two views of the egg, very much enlarged. At **c** is the cabbage looper or cabbage caterpillar. Above the letter **d** is shown the dark cocoon fastened to the cabbage leaf. What is the next stage after the cocoon? Where is the larva?

Metamorphosis in Insects

Many insects undergo a different kind of metamorphosis, which is a change from a wingless form to a winged form. The wingless form may live either in the water or on the land.

Insects reproduce as a rule by sexual union. The female then lays her eggs, usually a large number of them, in a suitable place. Some species lay the eggs in the water, some on leaves, and some in the bodies of other animals. The eggs hatch into the wingless larvæ. A great many larvæ are parasitic. They eat the plants or animals on which, or inside of which, they hatch.

Insects are covered by hard, horny coverings outside their bodies. In order to grow they have to shed this covering periodically. As the larva grows, wings begin to develop underneath the skin, but they do not come forth. The larva has many structures that the adult insect does not have, and the adult must have many (besides the wings) which the

larva has not. In the last stages of growth of the larva, his special organs do not grow, and the beginnings of the adult organs are formed.

Between the next to the last and the last shedding of the outer horny skin, all the larval organs disappear and are absorbed, and all the special adult organs grow to full size. The growth-changes are so great at this time that they use up nearly all the insect's vital energy. Eating and locomotion stop during this time. Often the insect ties itself to a leaf or twig or spins itself a cocoon. The insect in this stage of resting and metamorphosis is called the pupa.

Finally the insect comes out. In a few hours the wings enlarge to their full size, absorbing living material from the disappearing larval organs to do this, and also being filled with air for the same purpose. Then he flies away, a full-fledged adult.

Experiment 20. Find the larva or caterpillar of some insect. Notice what kind of leaves it feeds on. Make a box with a screen cover and a screen or glass front to put it in. Put a branch or a few sticks in the box. Feed the caterpillar the kind of food it usually eats until it becomes a pupa. Watch the development of the pupal covering, or cocoon, if one is formed. Find the pupæ of other insects and bring them to school, too. Finally one of these will open. Watch the adult insect come out. Observe the rapid filling out of the wings, and the disappearance of the larval organs.

Growth

Growth is regular and gradual. Even the metamorphosis by which an animal or plant radically changes its mode of life is prepared for by changes of structure that come about over a considerable period. We may pick out a single event, such as the germination of a seed—or the hatching of a hard-shelled egg, or the birth of a mammal, or the emergence of a frog from the water, or the breaking of an insect from the pupal covering—and fix our attention on the change, but we must not forget that this change in every case is the result of a long series of gradual growth-changes. From the moment the egg is fertilized, the new individual starts to grow. He grows continuously to maturity. There

may be a large change—a metamorphosis—at some period. But the important thing is the growth. At maturity, the organism produces others like itself, and these in turn begin to grow again.

Questions for Review, Discussion, and Study

Chapter VII

1. If you gathered some frog's eggs and kept them in natural surroundings for some time, and they never developed into tadpoles, what would you conclude?
2. Do we ever use the food storage of fish eggs as food?
3. What is it, in plants, that can be compared to the egg in animals? What are the similarities?
4. You have seen the word "metamorphic" used in two connections. What does the word mean?
5. Why is it inadvisable to put very young tadpoles in an aquarium with full-grown fish?
6. What does "amphibian" mean?
7. What do we mean when we say fishes are cold-blooded animals?
8. The horned toad lives in desert country where there is no open water. Do you suppose he is an amphibian?
9. Of the three tadpole features—gills, hind legs, forelegs—which appears first? Which last?
10. The tadpole or frog does not eat while the tail is being absorbed into the body. Where do you suppose he gets nourishment? Does he go without nourishment?
11. What striking differences are there between a frog's breathing arrangements and yours?
12. What hibernating animals do you know of beside the frog?
13. Do caterpillars ever die a natural death?
14. Is the cocoon of any insect useful to man?
15. Are the insects you most often encounter useful to man, or annoying to him?
16. Why is it well to know how insects grow and reproduce? (How about the mosquito, for instance?)

CHAPTER VIII

STIMULUS AND REACTION IN LIVING ORGANISMS

Irritability of Protoplasm

Living organisms maintain themselves by eating, drinking, breathing, and excreting waste products. They maintain their species by growth and reproduction. But they do more than this. They *adapt* themselves to new conditions and changes in the environment or surroundings. When they are stimulated they react; that is, they move, or they change their direction of growth, or they do something else to regain the correct relationship between themselves and the environment. In doing this they may make use of any or all of their organs. They may even stop some important function of metabolism or of growth for a time. This characteristic of living organisms is called irritability. It is, as we save seen, a basic function of all protoplasm. Irritability shows itself in the way all the life functions work together. When any one life function is disturbed, all the others may change in one way or another until the disturbance is at least partially overcome. For example, in man, an excess of carbon dioxide in the blood results in an increase of heart activity and more carbon dioxide is disposed of through the lungs.

In plants, and in the lower animals, the structure associated with the function of irritability is not very complex, nor very prominent. In the higher animals there is a more elaborate structure—the sense organs and the nervous system. The higher animals can see, hear, taste, and smell. They have a special sense of balance. In the skin are located sense organs of touch, pain, warmth, coolness, and pressure. The nervous system consists mainly of the brain, the spinal cord, and the nerves. This elaborate system of

senses and nerves enables the animal to act as a unit in responding to changes in the environment.

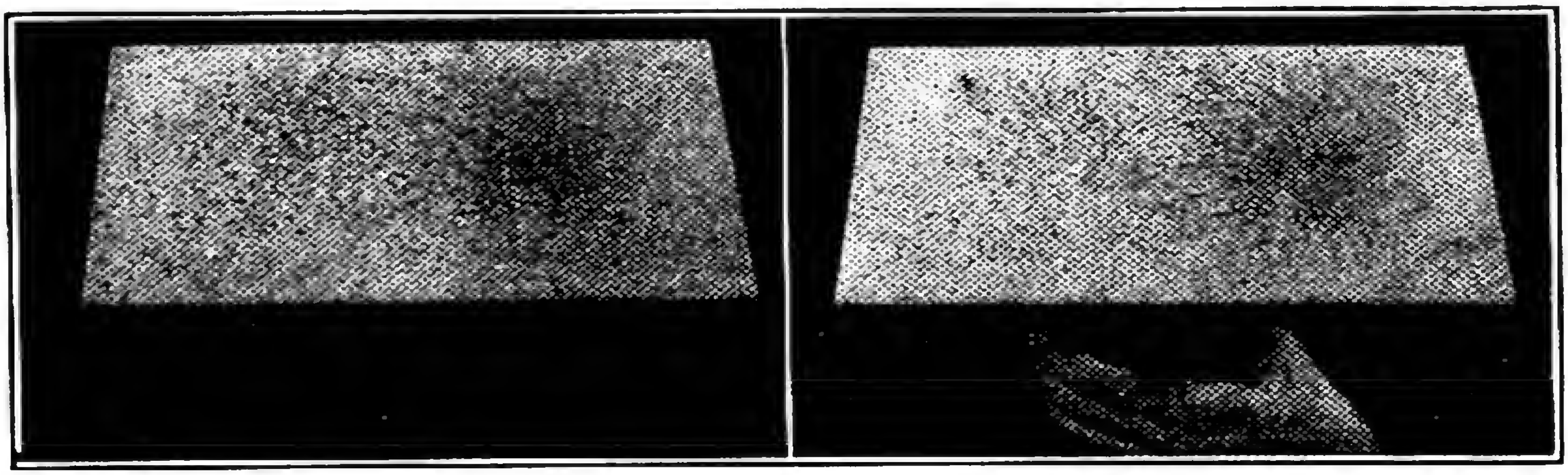
Experiment 21. Pupils should perform this experiment in pairs. One closes his eyes, facing away from the light, for about a minute or two, then facing the light, opens them. The other should notice how the pupil of the eye immediately becomes much smaller in response to the bright light. The enlargement is a slower process than the contraction.

Characteristics of Reaction

A stimulus is some sort of a disturbance—a change in the state of affairs about or within the organism. When an organism is stimulated, it does something to put itself in a condition in which its life processes can go on in their usual way. Thus when a person's finger is pricked, he jerks his hand away. The prick is a disturbance. It disturbs the usual state of affairs in the living cells of the finger. When the hand is drawn away, the finger can go on performing its natural functions.

The stimulus does not supply the energy used in the reaction. This energy comes from within the organism itself. The pin prick gets its efficiency as a stimulus not from the mere force of the push, but from the disturbing effect on the living organism. If a non-living object is knocked down it stays down. The mechanical equilibrium or balance is better in the lying-down position than in the standing-up one. But if an animal is knocked down, it jumps to its feet at once and either fights or runs away, as circumstances may dictate. The mechanical reaction to the blow ended when the animal was down. But the biological or life-reaction had barely started. It finished only when the organism was safe from any further attack that might interfere with its life processes. The energy for the mechanical reaction came from the blow and from the force of gravity. The energy for the biological reaction came from within the organism. It was supplied by the processes of metabolism. It is a well-known fact that when an indi-

vidual runs or does hard work he needs more food and more oxygen than usual. Hard manual workers eat more food than do others. The digested food and the oxygen combine in the cells, and set free the energy used in the reaction, just as the air and fuel combine by burning in an engine to give it its power.



Figs. 93a and 93b. In the first picture, iron filings have been sprinkled on a thin porcelain plate. Are they arranged in any very definite pattern? In the second picture the poles of a large horseshoe magnet have been brought underneath close to the plate. Notice the change. How would you describe it?

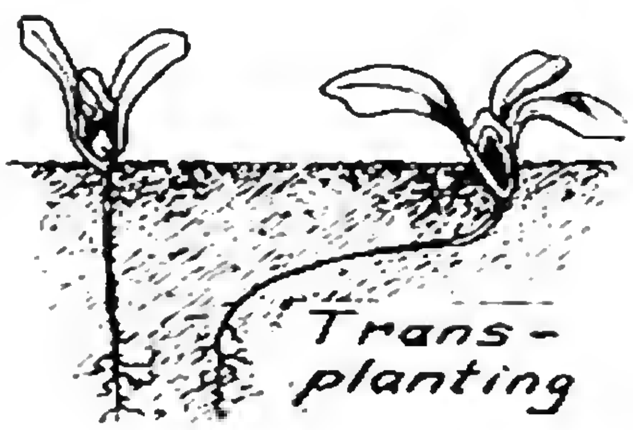
A biological reaction is an adjustment or turning or orientation in response to all the forces acting on the organism at a time. One of these forces may overshadow all others, as in the case of the pin prick or blow, but as a rule the behavior of an organism is a compromise between tendencies to react to this or that or the other stimulus, all at the same time. For purposes of study it is often necessary to look at just one stimulus, and the response of the organism to it, at a time. But in doing this we should not forget the influences of stimuli other than the one we are studying, on the total behavior of the organism.

Experiment 22. Sprinkle some iron filings on a sheet of stiff paper and bring a magnet under them. Note how they arrange themselves in a definite pattern. If now the paper is tipped, the pattern will change. The filings are now acting to establish a balance with respect to two forces: magnetism and gravity. Finally, if the tipping proceeds far enough, most of them will roll off. The force of gravity is

now stronger than the force of the magnet. Living organisms react to combinations of stimuli in somewhat the same manner, except that they show the characteristic difference of using energy generated within their own bodies to bring about necessary or valuable changes.

Tropisms

The word "tropism" comes from an old Greek word meaning, "I turn." A tropism is a type of reaction that is rather definite—one in which a given stimulus is almost always followed by the same response. Tropisms occur in both plants and animals. They occur even in the higher animals; man himself displays behavior of a tropistic sort.



(Courtesy U. S. Department of Agriculture)

Fig. 94. If a young plant is transplanted with its root lying horizontally in the ground, the root will turn and grow down again. What tropism does the plant exhibit?

The reaction in a tropism may be fast or slow. In animals it is usually quite rapid, being accomplished by means of the muscles of locomotion and movement. Plants do not have muscles, so that a tropic reaction in a plant is usually accomplished by changes in the rate or direction of growth of its different sides or parts. Tropisms in plants are relatively slow.

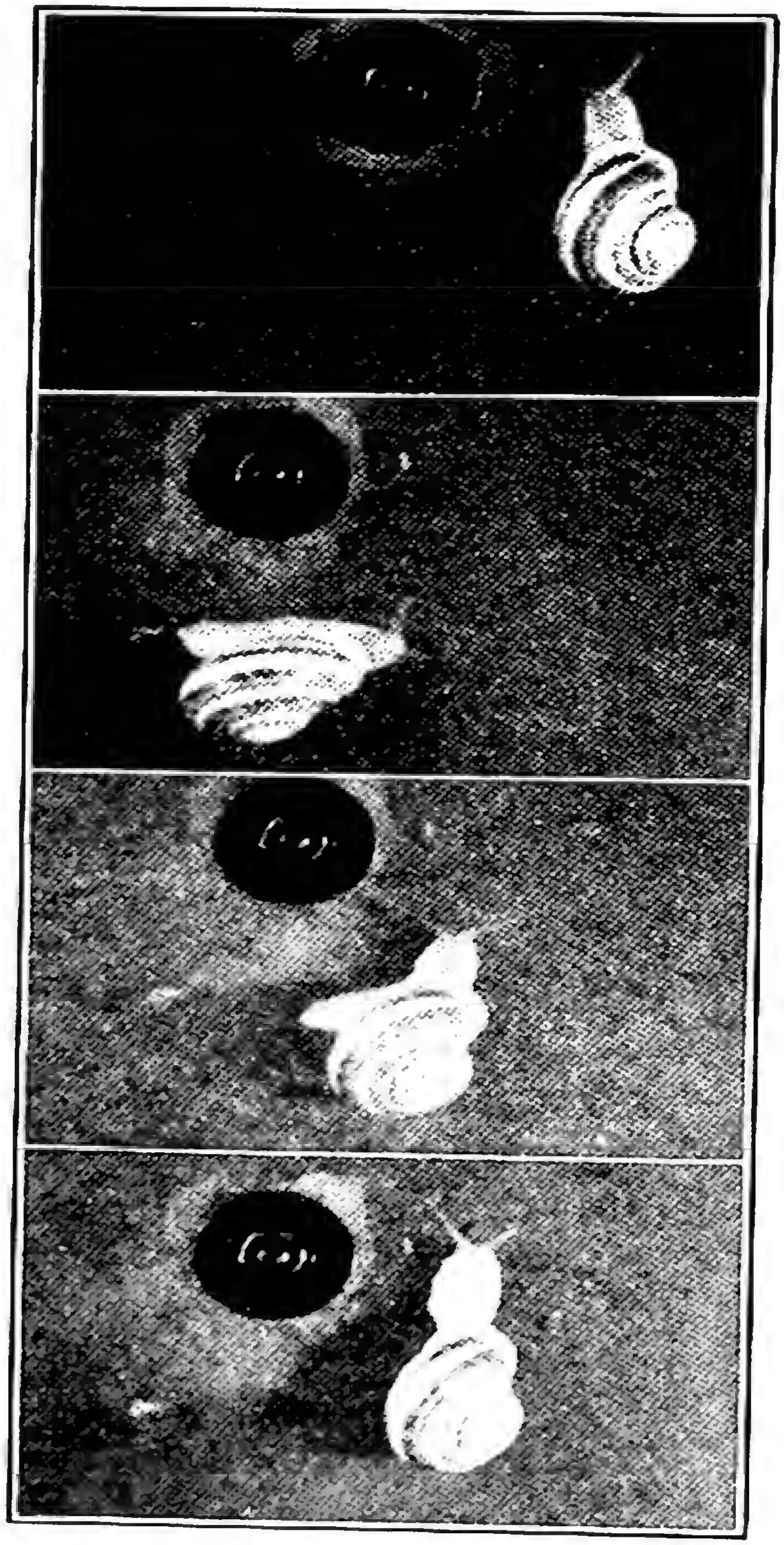
Tropic reactions are usually simple turnings toward or away from the source of the stimulus. If the organism tends to turn toward the stimulating object, the reaction is called a positive tropism. If it turns away, the reaction is called a negative tropism. Tropisms are classified, as a rule, by the type of stimulus. Thus a geotropism is a reaction to gravity; a positive phototropism is a tendency to turn and move toward the light, and a negative stereotropism is a drawing back from contact. There are many other types of tropisms, of course, but we shall consider these three as typical.

Geotropisms

Plants tend to send their stems upward and their roots downward.

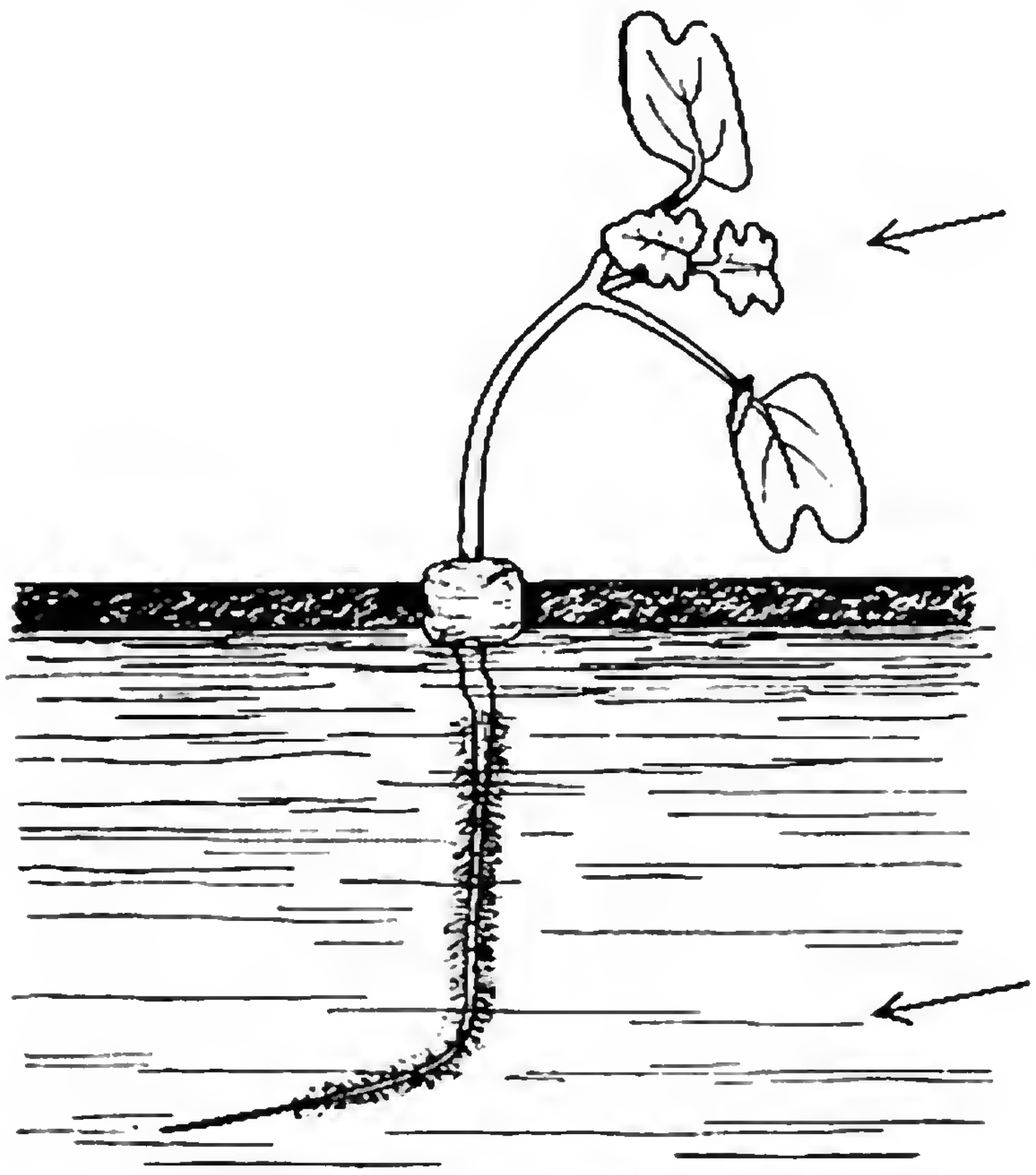
Experiment 23. Put some oats in a saucer of water and keep them in a dark place for six hours. Then plant them in a box which has a glass side. Plant them about half an inch deep and next to the glass. Keep the box in a dark place except when looking at it. Note that the root goes down, and the stem goes up. When the seedling is about an inch long from tip to tip, turn the box on its side and leave it again in the dark. The stem will turn and grow up, and the root will turn and grow down. What tropism is the plant exhibiting?

Animals also show a definite geotropism. Nearly every species, when placed on a slanting surface, tends to climb. If we place any small animal, such as a snail, on a large flat surface which is tipped, it will start at an angle for the top. If the surface is tipped in another direction, the snail will turn toward whatever direction has become upwards and continue to climb at the same angle as before. Other animals will behave in the same way. Even man has a tendency to seek the top of any slanting surface on which he may be standing. A person lost in the woods and afraid, almost always starts to climb uphill. If



Figs. 95a to 95d. A snail on a vertical glass plate which is pivoted so that it may be rotated. In the uppermost picture the snail is crawling straight up the vertical plate, undisturbed. In the next picture, the plate has been rotated in a clockwise direction through a quarter of a circle. The ensuing two pictures were taken at short intervals afterward. What tropism does the series illustrate?

asked why, he may reply that he wants to get to a high spot to look for landmarks, but as a matter of fact that is not the real reason. He is in a panic, reason has lost control, and he acts in accordance with the old fixed tendency to climb. Reason would tell him in every case to do just the opposite—to go downhill. In that direction lies water, and in that direction lies civilization. Settlements are almost always found in the valleys rather than on the tops of hills. Yet the person lost in the woods goes up. He is under the influence of the geotropism.



(After Strasburger)

Fig. 96. The root of this plant seedling is immersed in water, so that light may be made to shine upon it from the side. The arrows indicate the direction of the light rays. Note the effect on the root and also on the shoot. What do you suppose would have happened if the light shining on the root had come from the other side? What tropism is illustrated?

PHOTOTROPISMS

Plants grow toward the light; animals go toward it. The classical example is the sunflower, which faces the East at dawn and then gradually turns with the Sun until it is facing the West at sunset.

If oat seedlings are placed in a box where they can be illuminated from the side and not from the top, their stems will turn and grow toward the light and their roots will turn and grow away from it. If the stem is illuminated from one side and the root from the other side, the stem and root will both turn toward the same side; the stem toward its light, and the root away from its.

The stem is positively phototropic and negatively geotropic, while the root is negatively phototropic and positively geotropic. These facts may be checked by experiment.

Animals tend to move away from dark places and toward light places, also. Even the little paramecium swims away from dark places in the water toward those where the sun shines. If a room is full of flies, an easy way to get rid of most of them is to close all the doors and windows and pull down the shades, making the room dark. One window on the sunny side must be opened just a few inches. In a short time most of the flies will go out of the room through this lighted opening. Man himself dislikes dark places, and tries to stay in the light. Nearly all children are afraid of the dark without any real reason, and some have considerable trouble in overcoming this useless fear.

(Courtesy U. S. Department of Agriculture)

Fig. 97. These Brown-tailed Moths have collected around the base of an electric light pole. Did they come here in the day-time or at night? What tropism do they exhibit? Do most of those on the pole face the same way?

Stereotropisms

Organisms respond to touch or contact. As a rule the tendency is to approach and remain touching something; but if a contact is sudden, withdrawal occurs. Plants and animals both have stereotropisms. If oat seedlings are touched several times on one side, they grow toward that side. The same tendency in exaggerated form explains the tendrils or twining branches of certain climbing vines. Contact between one side of the young branch and the tree or string or pole about which it is growing causes it to grow toward the side touched. In time it grows round and round the supporting structure, and it is thus able to climb much higher than it could if its own stem had to support its weight. If the branch is touched on both sides at once it will not turn in either direction.

Animals also try to keep in contact with solid objects. Nearly everyone has noticed how mice run along the floor close to a wall. Human beings also tend to keep close to something solid. How many people walk down the middle of a stairway when they can walk near the wall or the railing? And how many sit in a chair in the middle of a room when they can move it near a wall?

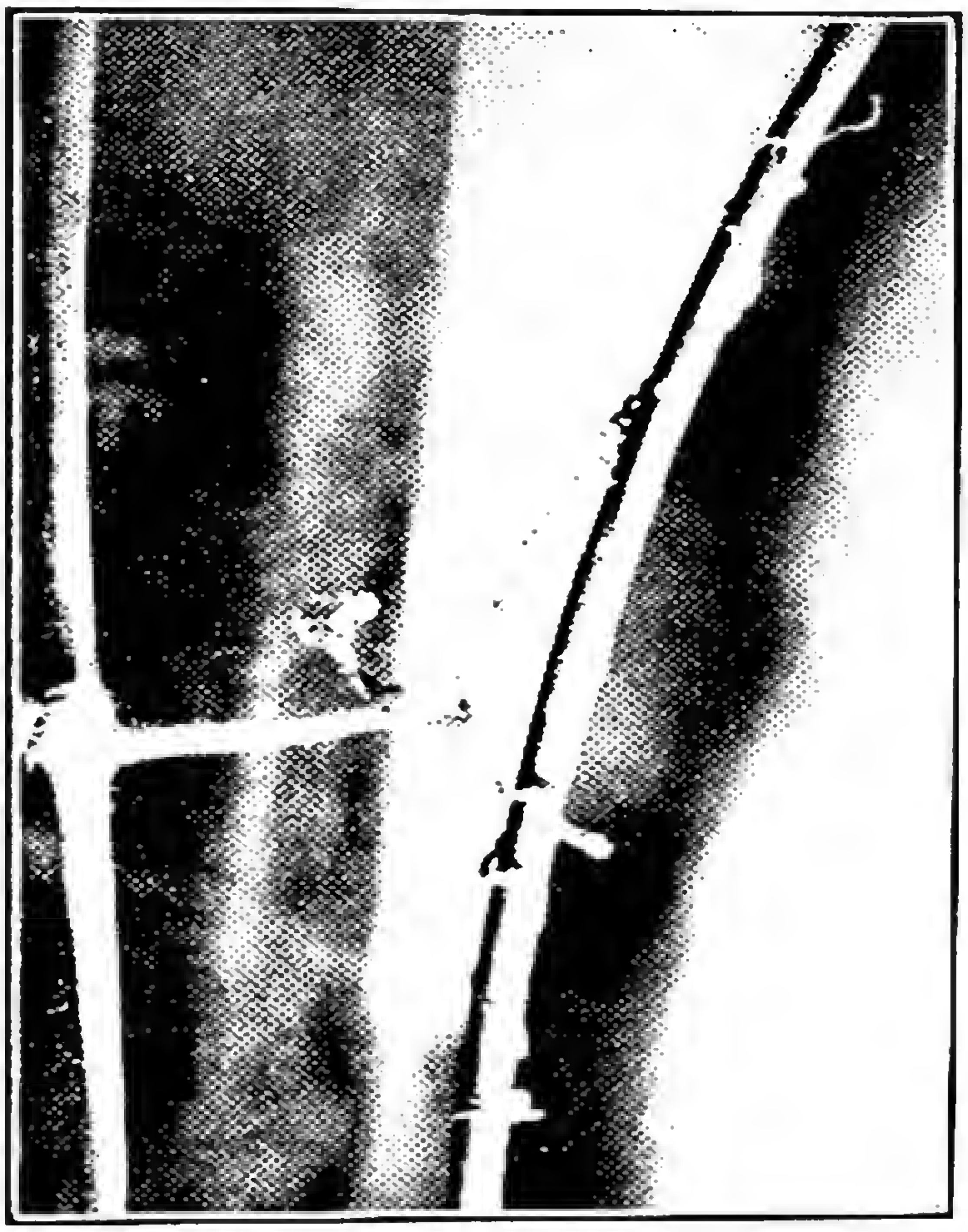


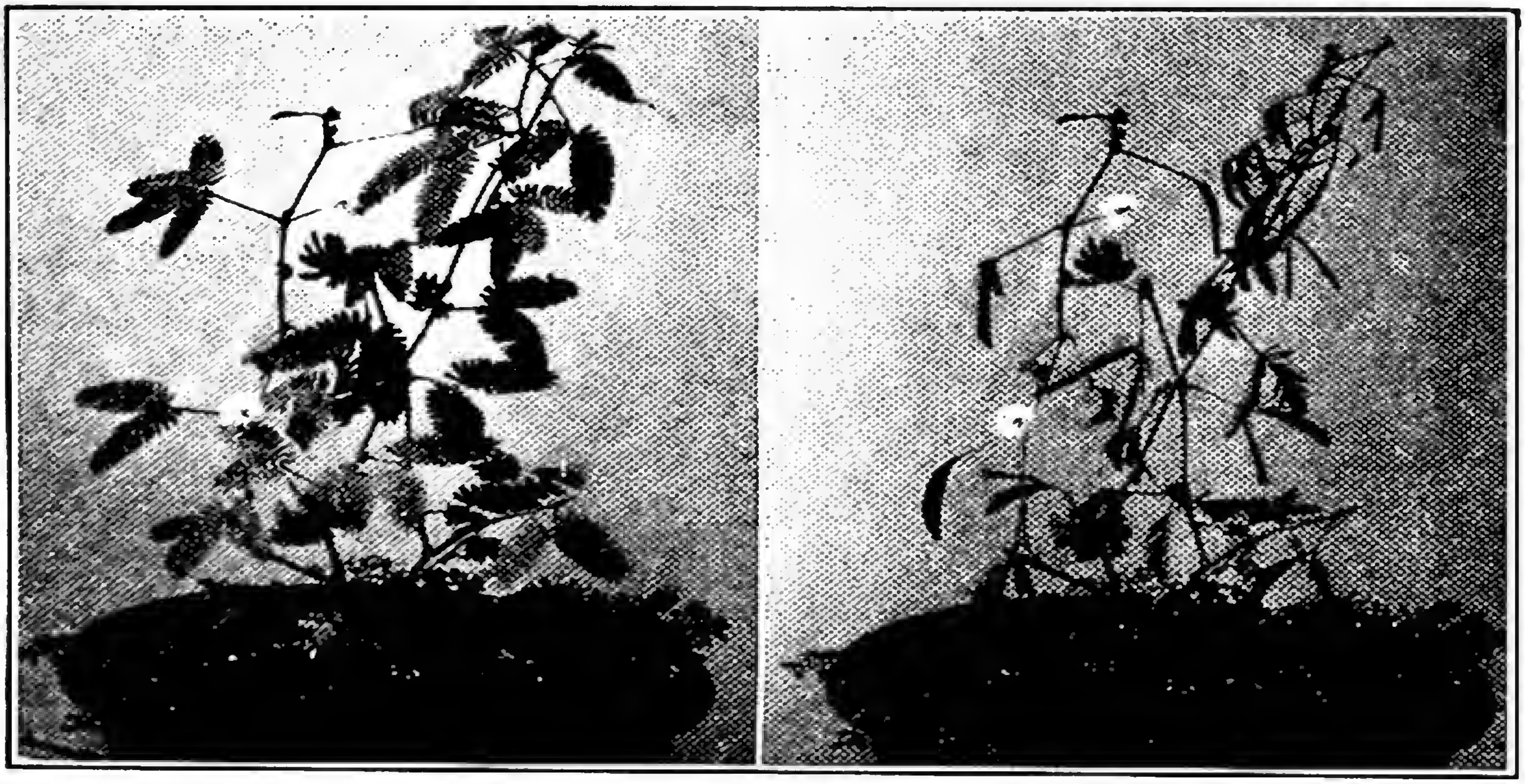
Fig. 98. Notice the way the tendrils from the plant on the left have twined themselves about the wire shown on the right. What tropism is being exhibited? How can you account for the curls in the tendril that does not touch the wire?

Higher Reactions

We have studied only the tropisms so far. These are the simplest forms of reaction, and occur in both animals and plants. They are definite reactions to definite forms of stimulation. If two or more stimuli strike the organism at the same time, the reaction is a simple compromise. We have noted this in the case of the geotropism and the phototropism in plants. If a seedling is touched ten times on one side and three times on the other, it will bend toward the side touched ten times, but not as sharply as if it had not been touched three times on the other side.

In the higher animals—those whose nervous systems include brains—the behavior at any time is not a simple compromise between a set of fixed tendencies to react in definite ways to particular stimuli. Much more than this is involved. The higher animals are able to change their reactions to stimuli. These changes are called learning.

Plants and the lower animals always make the same response to a particular form of stimulus, whether the apparent aim of the reaction is achieved or not. This is the characteristic of tropisms. But if reacting in a certain



(Courtesy Harvard Botanical Museum)

Fig. 99. The mimosa—a "sensitive plant." At the left, the plant undisturbed. At the right, the same plant a few seconds after having been stroked by a human hand. Do you suppose stroking with any other object would produce similar results? Why are such plants called "sensitive plants?" Aren't all plants sensitive? What tropism is illustrated by the behavior of the mimosa?

way to a stimulus produces unsuitable or harmful results in one of the higher animals or in man, he soon *learns* to avoid this reaction, and to respond in some other way that will bring achievement. The higher animals also inherit the ability to make an indefinite response to a stimulus. The stimulus causes the organism to move, but the movements are not directed. Finally some movement succeeds in producing a suitable result. Soon the animal learns to make that movement whenever the stimulus is received. Suppose for example that someone wants to learn to catch

a ball. As the ball approaches, a very common reaction is to spread the hands apart and try to clap them together on the ball, one from each side. The result is usually failure. If the hands are clapped together too soon the ball hits the ends of the fingers, producing a painful injury. If they are clapped together too late, or not hard enough, the ball slips through and hits the face or body. Other methods are tried. One hand is held behind the approaching ball and the other clapped over it as soon as it touches. This method works. The timing of the motions need not be so fine. Even if the second hand is not clapped over the first in time, there is little danger of injury. Success fixes the correct habit in a short time.

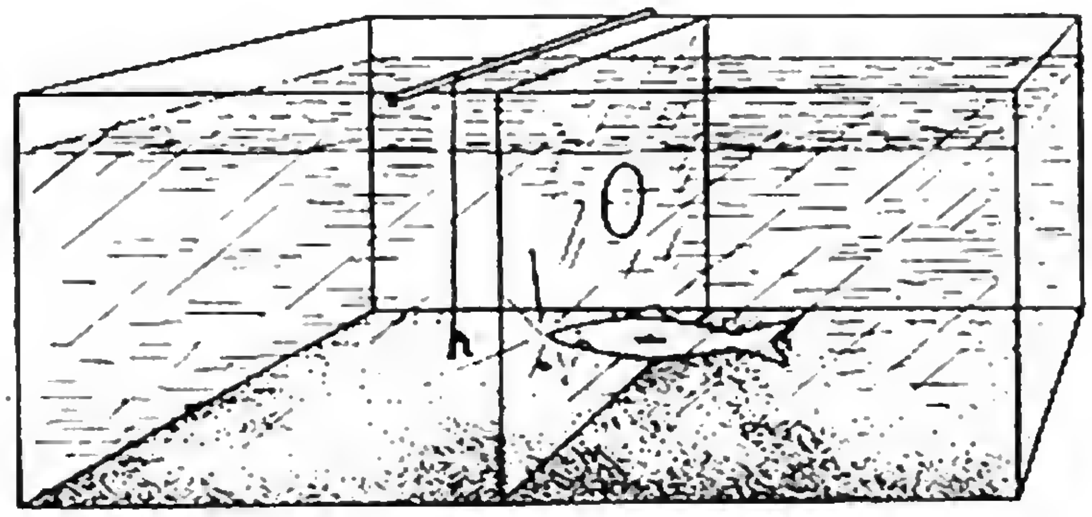


Fig. 100. A fish in a problem tank. The problem for the fish is to get at the food. He cannot solve the problem. If he happens to go through the hole in the partition and get the food enough times, he may finally learn to go directly to the hole when he wants to get through. But it will take many trials to learn this. Do you think the fish is very intelligent?

Tropisms always result in a direct turning toward an object or stimulus to be approached, or a direct turning away from a stimulus to be avoided. If the shade in a well-lighted room is raised on a dark night, insects will dash time and again against the glass in the response of the phototropism. The higher animals would not do this more than once or twice if at all.

One of the strongest tendencies is that which leads toward food. Suppose a fish is placed in a tank having a glass partition in the middle with a hole in one end big enough for it to swim through. If food is placed in the tank on the other side of the partition, the fish will swim straight at the food until he bumps his nose on the partition. It will only be by chance that he will eventually go through the hole and get the food. He may bump the glass partition many times before he learns to avoid it.

Suppose, however, that a dog is taken into a house and the door left open. A piece of meat is thrown out a window, which is then closed at once. The dog will not try to jump through the glass. He will turn at once, run out through the door, and around the house to the meat. His action shows intelligence; that of the fish much less. The dog's intelligence here consists in the ability to see the situation as a whole, discard *without trying them,* reactions that would be useless and proceed at once toward the object by a path that will result in success, even though it leads at first directly away from the thing he wants. This is one of the simplest examples of intelligent action. It is by the use of his very much greater intelligence that man has made himself the master of all other living things.

Questions for Review, Discussion, and Study

Chapter VIII

1. Do we mean the same thing when we say protoplasm is irritable, as we do when we say a person is irritable?
2. What organs do you make use of when you adapt yourself to the "dinner on table" situation?
3. What organs does the paramecium make use of when he adapts to the "sunlight in neighborhood" situation?
4. Do you suppose "goose flesh" in cold weather is a response to a stimulus? What is the stimulus? What part of the body is sensitive to it?
5. Can you think of this question as a stimulus? How do you first respond to it?
6. Does a stimulus have to be a violent disturbance? How about darkness as a stimulus?
7. Is a stimulus always an exciting one? How about lullabies? Warm milk?
8. A boy says a certain thing is alive "because when you do something to it, it does something back." Give one word naming the characteristic the boy is referring to.
9. What very important difference is there between the reaction of iron filings and reacting in an organism?
10. Does an organism ever react in a way characteristic of inanimate matter?

11. As you read this, are you being affected by just one stimulus, or by a number of stimuli? Does the light have any effect on your reading? Are you comfortable? Does it make any difference whether you are or not?

12. "Helio" refers to the Sun. Can you give a reasonable explanation for applying names "heliotrope" and "sunflower" to those plants? What sort of reaction would heliotropism be?

13. When sprayed with "Flit," a cockroach near a wall will run to the wall and climb up. We cannot be sure this is a tropism. But if it is, what tropism would you call it?

14. Of what importance might negative phototropism be to the cockroach?

15. If you touch a paramecium, he will move away. What tropism is he exhibiting and in which form—positive or negative?

16. An infant will grasp whatever touches his palm. This is probably not a tropism. But if it were, what kind would it be? Would it be called positive or negative?

17. The first time a red-hot iron is presented to an infant, he may seize it. The tenth time, he won't. What do we call this change in his mode of response?

18. What do we say of an animal which is able to improve his modes of response to stimuli?

19. Have you ever learned anything by accident? How did it happen?

20. In what phase of your life do you ordinarily consider intelligence to be most important? Is it also important in other situations?

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